UNCLASSIFIED

Copy

IDA PAPER P-3172

ASSESSMENT OF OPTIONS FOR ENHANCING SURFACE SHIP ACQUISITION

DTIC QUALITY INSPECTED 4

L. D. Simmons, *Project Leader*

March 1996

Prepared for

Under Secretary of Defense (Acquisition and Technology),
Strategic and Tactical Systems (Naval Warfare)
and
Defense Advanced Research Projects Agency

19960930 113

IDA

INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

UNCLASSIFIED

IDA Log No. H 96-000185

The work was conducted under contract DASW01 94 C 0054 for the Office of the Under Secretary of Defense. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

UNCLASSIFIED

IDA PAPER P-3172

ASSESSMENT OF OPTIONS FOR ENHANCING SURFACE SHIP ACQUISITION

L. D. Simmons, *Project Leader*
C. P. Hammon
R. E. Kuenne
J. W. Lisanby
N. I. Om
D. A. Rains
K. J. Saeger
K. W. Tyson
H. Williams

March 1996

Approved for public release; distribution unlimited.

IDA

INSTITUTE FOR DEFENSE ANALYSES

Contract DASW01 94 C 0054
Task T-F1-1271
DARPA Assignment A-194

UNCLASSIFIED

PREFACE

This study was performed by the Institute for Defense Analyses in response to requests from the Office of the Under Secretary of Defense Acquisition, Strategic and Tactical Systems[1] and the Director Defense Advanced Research Projects Agency (DARPA).[2] Mr. John McGough, Naval Warfare Systems, and Mr. Gary Jones, DARPA, served as project managers for the task; their efforts to assist us were considerable and are hereby gratefully acknowledged. The authors also acknowledge the insightful and constructive guidance provided by the IDA Technical Review Committee—Dr. David R. Graham, Dr. J. Richard Nelson, Dr. Karen J. Richter, and RADM Grant A. Sharp, USN (Ret.), all of IDA; CAPT. Barry Tibbitts, USN (Ret.) of J.J. McMullen Associates—and its chairman, Dr. David L. Randall, Director of IDA's System Evaluation Division. In addition, the authors acknowledge the assistance provided by the Department of Defense and a considerable portion of the U.S. shipbuilding industry. The study team met with numerous representatives from the Office of the Secretary of Defense, the Department of the Navy, other U.S. Government agencies, U.S. shipbuilders, and the design firms and professional associations involved in building ships for the Navy. Their open and in-depth responses to our inquiries added measurably to our understanding of the complexities of designing and building modern warships and managing their acquisition. Representatives from several foreign shipyards were kind enough to provide information regarding their operations.

---

1 *Alternative Surface Ship Acquisition Strategies*, Contract DASW01-94-C-0054, Task T-F1-1271.

2 *Alternative Surface Ship Acquisition Strategies*, DARPA Project Assignment No. A-194.

This page intentionally left blank

CONTENTS

Appendixes

This page intentionally left blank

LIST OF FIGURES

This page intentionally left blank

LIST OF TABLES

This page intentionally left blank

Part 1

INTRODUCTION AND SUMMARY

INTRODUCTION

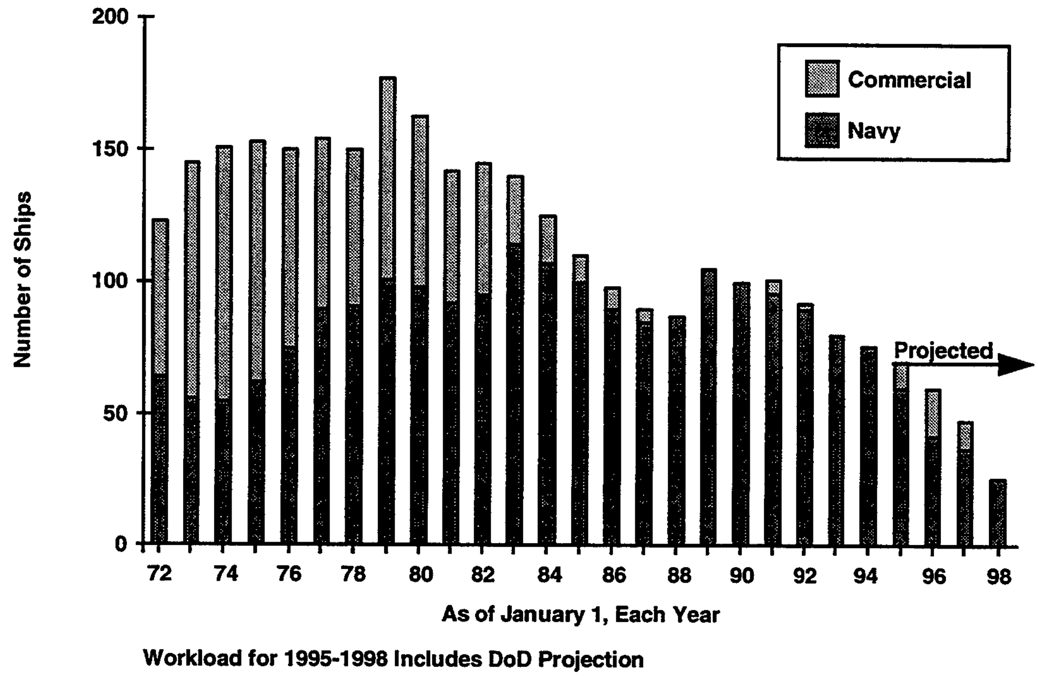
A. BACKGROUND

Modern naval surface ships are among the most complex systems ever designed and built by humankind. A typical warship contains several hundred subsystems and tens of millions of parts, requires up to 10 years to design, and costs somewhere between several hundred million and several billion dollars.

In the United States, such ships are now built in only a handful of shipyards. With the reductions in the overall size of U.S. military forces that have come with the end of the Cold War, the number of ships needed by the Navy has decreased as well. Although the major yards currently have orders on backlog, many of these ships were ordered before the recent dramatic decline in funding for new ship construction. The existing labor force at the yards will easily work off this backlog within the next several years. As a result, the available construction capacity at the major U.S. shipyards seems certain to exceed expected demand unless dramatic changes occur.

Until the early 1980s, the yards that now build ships for the Navy also built the significantly less complex and less costly ships that are used to transport commercial cargos. However, the combination of the increased demand for naval ships that resulted from the Reagan buildup's rising defense budgets, a concurrent decrease in the worldwide demand for commercial ships, and the elimination of maritime subsidies resulted in the virtual disappearance of ocean-going commercial ship construction within the U.S. shipbuilding industry (see Figure 1). Consequently, the largest U.S. shipyards have little recent experience in building commercial ships and thus seemingly limited prospects for substituting increased commercial production for declining naval construction. To help remedy this situation and improve the commercial construction capabilities in U.S.

shipyards, the U.S. Government established the *National Shipbuilding Initiative.* As part of this program, the Defense Advanced Research Projects Agency's (DARPA) MariTech Program provides matching funds for shipyard initiatives in commercial construction.



Source: Marine Log

* The number of ships under construction or on order includes ships in all stages of construction as well as those that have been funded but for which construction has yet to start. Consequently, this value provides a measure of the total shipyard workload at any point in time. The number of Navy ships ordered or delivered in any given year can be roughly estimated by dividing the number of Navy ships shown for that year by the average time needed to build a Navy warship, which is on the order of 5 years.

Figure 1. Number of Ships Under Construction or On Order in U.S. Shipyards

In addition to concern regarding the overall health of the shipbuilding industry, OSD has had long standing concerns regarding the seemingly high cost of building naval ships and shipyard productivity measures that appear to lag behind the levels attained in the most modern foreign shipyards. The prospect that the Defense Department's acquisition reform initiatives could benefit ship acquisition has raised additional questions. To address these concerns, OSD asked IDA to identify and assess options for improving ship acquisition, taking into account the significant recent changes in the strategic, budgetary, and acquisition oversight arenas.

B. OBJECTIVE

Specifically, OSD asked IDA to identify and assess acquisition strategies and approaches that would enable effective and efficient Navy ship procurement while helping to strengthen the nation's shipbuilding industry. Particular attention was to be paid to the following aspects of the ship acquisition process: the acquisition strategy employed by the government, the ship design and production practices employed by the Navy and the shipyards, and the potential implications of increased commercial construction.

C. APPROACH

To accomplish this objective, the study adopted the approach outlined in Figure 2. In order to assess the various factors identified in the figure, the team conducted an extensive literature review, attended national and local conferences focused on the future of the U.S. shipbuilding industry, and conducted numerous interviews and discussion sessions with personnel from a wide range of government agencies, Navy ship program and program oversight offices, and selected shipbuilders. The team also visited shipyards in the United States as well as those in several other nations. The specific organizations and enterprises contacted during the study are identified in Table 1. To supplement these qualitative assessments, the team carried out a statistical analysis of ship program cost and schedule data from the DoD *Selected Acquisition Reports* (SARs).

D. LIMITATIONS

As indicated in the previous section, the study's assessment of options for improving ship acquisition is primarily qualitative in nature. Although program cost and schedule data from the Department of Defense Selected Acquisition Reports were used to assess how changes in acquisition management have affected ship programs in the past, the study team identified little if any numerical data on which to base a quantitative assessment of how changes in the way ships are designed and built or their acquisition managed by the government would affect future programs. The study is further limited in that IDA has not estimated the costs that would be incurred in order to change any of

these aspects of the overall ship acquisition process. Nor does the study examine whether changes are warranted in the laws and statutes that apply to the shipbuilding industry. Given the high visibility of the shipbuilding industry, the Congress has taken a keen interest in overseeing and guiding ship construction programs in recent years, beneficially in some instances, detrimentally in others.

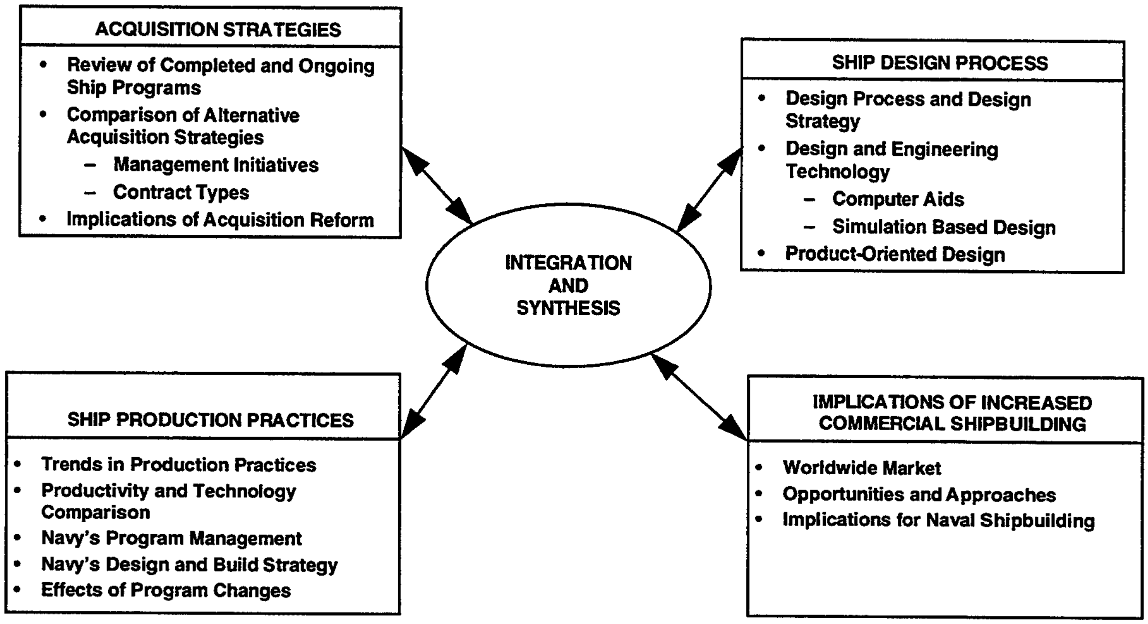


Figure 2. Study Approach

Finally, it is worth noting that while we have based our findings and conclusions on the information that was available to us, our view is necessarily influenced by our individual and collective experience both during the study and, for several study team members, from life-long careers in the shipbuilding industry.

E. ORGANIZATION OF REPORT

The report is organized into two parts. The first consists of this introduction and the summary that immediately follows. Part 2, Analyses, comprises four chapters that detail the study's examination and assessment of (I) the management and oversight processes by which the U.S. Government acquires naval ships, (II) ship design practices,

(III) ship production practices, and (IV) the prospects for and potential implications of increased production of commercial ships. Additional details are reported in several appendixes.

Table 1. Organizations and Enterprises Contacted During Study

OSD USD(A&T) Naval Warfare Systems USD(A&T) Acquisition Program Integration USD(A&T) Acquisition Reform PA&E	**U.S. SHIP YARDS** Avondale Bath Ingalls McDermott NASSCO Newport News
DARPA Maritime Systems Technology MARITECH Simulation Based Design	**FOREIGN SHIPYARDS** Blohm & Voss Odense-Lindo Howaldswerke Deutsche Werft Burmeister & Wain Ishikawajima Heavy Industries (IHI)[a] Kawaski Heavy Industries (KHI)[a] Mitsubishi Heavy Industries (MHI)[a] Bazan (Spain)[b] Rauma (Finland)[b] Mitsui Engineering and Shipbuilding (Japan)[b]
NAVY OFFICES DASN(RDA) Ship Programs Office of the Chief of Naval Operations NAVSEA Specialty Codes (Contracts, Design, Surface Ships) Ship Program Offices Acquisition Reform Ships Support Office NSWC Carderock Division Office of Naval Research Supervisors of Shipbuilding Bath New Orleans Newport News Pascagoula	**OTHERS** Maritime Administration (MARAD) National Research Council Shipbuilders Council of America American Shipbuilding Association Design Firms John J. McMullen University Researchers Investigating Complex Processes CAD/CAM Information Management

[a] Yards visited in conjunction with previous research.
[b] Trip reports obtained for visits by NAVSEA personnel.

This page intentionally left blank

SUMMARY

A. FUTURE PROSPECTS

An obvious consequence of a smaller military is that fewer weapon systems need be bought in any given year to equip the force. This is as true for ships as it is for aircraft, tanks, or trucks. Projected Navy surface ship requirements for the next 20 years average only 6 or 7 ships per year,[1] or about half the number built each year between 1985 and 1995. Because the current shipyard labor force and shipbuilding capacity in the United States were sized to accommodate a larger fleet, the future would appear to promise significant readjustments as manufacturing capacity adjusts to conform with projected demand.

To lessen the severity of these readjustments, the U.S. Government and a substantial portion of the U.S. shipbuilding industry are considering increased commercial construction as a means to maintain the viability of the industry. The extent to which this is possible depends both on the substitutability of commercial ships for naval and the ability of U.S. shipyards to re-enter the highly competitive commercial shipbuilding market from which they withdrew over a decade ago.

That commercial ships are not directly substitutable for naval ships is illustrated in Table 2. Navy ships are typically fitted with a variety of high technology weapon and sensor systems. Installing these systems, providing accommodations for substantially larger crews, and including the more comprehensive survivability features required for modern warships entails considerably more outfitting than is needed for even the most complex commercial ships (e.g., cruise ships, product tankers, or liquid natural gas

---

1 Based on the Navy's shipbuilding plans through 2015 as provided by N81 on 7 March 1996.

carriers). As a consequence, roughly 5 to 10 times as many employee-years are required to build the typical naval combatant as are needed to build a commercial ship. Moreover, the labor force needed to assemble a warship includes a larger proportion of skilled workers than is the case for commercial ships. To maintain the overall size of the current shipbuilding labor force in the face of the projected 50 percent reduction in the number of Navy ships bought each year would require construction of over 50 commercial ships annually. Even if this were accomplished, differences in the type of work needed would entail adjustments in the labor force as less-skilled laborers replace some of the electricians, pipefitters, and other outfitters involved in naval ship construction.

Table 2. Differences Between Naval and Commercial Ships

Characteristic	Naval Combatant	Commercial Ship
Displacement	3,000 - 10,000 tons	25,000 - 500,000 tons
Structure	1,000 - 4,000 tons high strength steel, aluminum, composites	8,000 - 50,000 tons low strength steel
Ship Crew	200-400	15-30
Ship Payload	Integrated, high-technology, high-value weapon and sensor systems	Cargo
Arrangements	Every area of ship densely packed with equipment, cables, pipes, ventilation	Machinery space relatively uncongested, balance of ship is large empty cargo space
Ship Signature Treatment	Extensive noise reduction, extensive radar and IR signature reduction	None
Survivability Features	Redundant systems throughout ship, extensive shock hardening, extensive fire fighting	Must meet U.S. Coast Guard requirements
Life Expectancy	30-40 Years	15-30 years
Shipyard Employment Required To Build 2 Ships Per Year	6,000 - 8,000	800 - 1,000

* Based on material contained in [Bath Iron Works, 1994].

Table 3 identifies a number of other important considerations that are likely to impede direct substitution of commercial construction for naval shipbuilding, at least at the level required to sustain current shipyard employment.

Table 3. Considerations Affecting Substitutability of Commercial Ship Construction for Naval Ship Construction

Consideration	Naval Ship Construction	Commercial Ship Construction
Entity Responsible for Ship Design	Currently done by Government through contract design, yards do detail design	Shipyard
Shipbuilding Facility	Low volume steel capacity, small building berths, highly integrated outfitting shops	High volume steel capacity, large building berths, limited outfitting shops
Subsystem Vendor Relationships	Competitive	Long term
Oversight by Ship Buyer	Extensive	Minimal
Extent of Competition	Limited	Global
Profit Margin	Predictable	Volatile

Whether the major U.S. shipbuilders, who have built few commercial ships over the last decade, could win contracts for 50 or more commercial ships each year in the face of a highly competitive market is questionable. Consequently, this paper explores a variety of other options for ensuring that the Navy can continue to obtain the high quality warships it needs at affordable cost and within reasonable schedules. In particular, the study examines means to improve the processes by which the Government manages the acquisition of Navy ships, the processes by which ships are designed and built, and the prospects for and implications of increased commercial construction, albeit at lower levels than would be needed to sustain the industry at is current size. The principal findings of these assessments are reported in the sections that follow.

B. OVERALL ASSESSMENT

Of the options examined — acquisition management, design and production practices, and increased commercial production — none alone is likely to provide the improvements in efficiency or economic prospects sought by the Navy, OSD, or the shipbuilding industry itself. In short, there is no single simple means for improving the Navy's ability to acquire the type ships it considers essential within desired cost and schedule limits. Advances on many fronts will be required to ensure efficient and effective

ship acquisition for the Department of Defense and improve the overall economic prospects for the shipbuilding industry.

Fortunately, *the entire U.S. shipbuilding community* (comprising the Navy, OSD, other parts of the Government, and the shipbuilding industry) *seems acutely aware of the problems that confront the industry and has underway a wide range of actions to enhance the industry's ability to weather the impending crisis.* The National Shipbuilding Initiative and its principal components — the DARPA Maritech Program and the Maritime Administration's (MARAD) Office of Shipyard Revitalization — provide a clear indication of the Government's intentions as well as direct financial support to enhance commercial shipbuilding capabilities within the industry.[2] Additional important work is being done under the aegis of the National Shipbuilding Research Program (NSRP). Important studies have been conducted by the National Research Council, NATO, the Center for Naval Analyses, and the Navy.[3] The problem has also been the focus of one or more American Society of Naval Engineers (ASNE), Marine Log, and Society of Naval Architects and Marine Engineers (SNAME) conferences each of the past several years.[4] These efforts are valuable and should be continued.

To ensure that the necessary changes are implemented, however, the Navy should establish a government-industry team to identify desirable ship acquisition improvements and oversee their implementation within the Navy and, when appropriate, to encourage their adoption by the shipbuilding industry. Given the breadth and scope of the changes needed, the team should be situated at an appropriately high level within the Navy hierarchy. The Deputy Assistant Secretary of the Navy (Research Development and Acquisition) [DASN(RDA)] Ship Programs appears to us to be properly positioned to take on and execute this responsibility. The *DDG 51 Acquisition Study* [Kiss and Valdes,

---

2 These efforts are described in [President, 1993], [Shaffran, 1995], and [MARAD, 1995].

3 Results of these studies are reported in [NRC, 1995], [Stewart, 1995], [NATO, 1994], [Rost and Tighe, 1992], [BDM, 1994], and [Kiss and Valdes, 1995].

4 Conference proceedings are reported in [ASNE, 1995], [Marine Log, 1994], [Marine Log, 1995], [SNAME and ASE, 1992], [SNAME, Jan 1995], [SNAME, Oct 1995], and [SNAME, Feb. 1996].

95], recently completed under the aegis of DASN(RDA) Ship Programs, exemplifies the type activities we would envision being undertaken by the proposed team. Additional staffing and funding will probably be required in order for DASN(RDA) Ship Programs to assume this role, but we have not determined the levels.

The specific approaches and concepts for improving ship acquisition that appear to us to merit continued support or adoption are identified in the paragraphs that follow. To facilitate the location of amplifying information, references are provided to the appropriate sections of the detailed analyses contained in Part 2.

C. ACQUISITION MANAGEMENT

Design requirements and specifications should be simplified to the extent possible. Use of a circular of requirements in lieu of today's highly detailed specifications would help to encourage innovation and adaptation of commercial-grade systems and components — and in some cases, even entire ship designs — to military needs. Overstatement of requirements drives up cost by preventing consideration of what might otherwise be reasonable tradeoffs. While the long ship production cycle presents obstacles to the kind of evolutionary development possible with other types of weapon systems, a variety of tradeoffs can and should be made. Within the constraints imposed by the need to provide specific military capabilities, commercial standards and practices should be adapted to naval ships as should already proven systems and technologies. [Chapter I, Section D]

With close cooperation between the government and the shipbuilder, *cost-plus contracts are likely to lead to the best outcomes for lead ship design and construction.* Fixed-price development contracts should be discouraged. Forcing the shipbuilder to "bet the company" to participate in a program can backfire against the government. The government should pay reasonable costs during development and should assist the contractor in making design tradeoffs. Once there is construction experience with a ship class and costs are well known, risk sharing makes sense. *For later versions of a ship*

class, fixed-price-incentive-fee and fixed-price-award-fee contracts should be used. Incentives can be targeted toward cost reduction, maintainability, quality, or other concerns based on fleet experience. In the current budgetary environment, the potential benefits of having two yards compete through detail design need to be weighed against the cost and schedule benefits of down-selecting to a single yard as early as possible. Table 4 identifies important considerations that would need to be taken into account when deciding whether to opt for competition or early down-selection to a single shipyard. [Chapter I, Section D]

Table 4. Competition versus Early Down-Selection

Factors Favoring Competition	Factors Favoring Early Down-Selection
Lower prices likely, especially if shipyards believe that their survival is at stake	Makes early industry involvement in IPPDT process easier
Prevents shipyard monopoly, which would most likely lead to higher prices	Can still compete at subsystem level
Increases surge potential, both for current and future programs	More consistent with down-sized industry
Creates incentives for effective design	More orderly program management
Creates incentives for maintainability	Avoids upfront costs of establishing dual capability
	Incentive fee and award fee contracts may be effective (needs rigorous examination)

Figure 3 outlines an acquisition management approach that accommodates these and other desirable features. The wide ranging tradeoff studies included in the concept formulation phase are intended to explore the relationship between ship performance, combat effectiveness, and costs along the lines of OSD's Cost As An Independent Variable initiative. That reductions in design requirements can lower ship cost is, of course, obvious. The difficult task is to determine the extent to which combat effectiveness will be degraded by the consequent reductions in ship performance. The early tradeoff studies should be structured to address this issue.

Many of the other elements of the approach outlined in Figure 3 are already being implemented in the acquisition management structure developed for the LPD 17 Program, and in the structures being considered for the SC 21, ADC(X), and Arsenal Ship

Programs. The Navy should seek to learn as much as possible from these innovations and then adopt the most beneficial elements as the standard for future ship acquisitions. [Chapter I, Section C]

Concept Formulation Undertaken by Navy
- **Ship Requirements Set by Careful Tradeoff Analysis**

Navy-Led Product and Process Development Team Established To Integrate Design and Development, Yards Included on Team

Simplified Requirements Process
- **Circular of Requirements (COR) Used in Lieu of Specifications Whenever Possible**
- **Commercial Standards and Practices Emphasized**

Design Competition Conducted, Bidders Prepare Contract Designs

Winning Shipbuilder (or Industry Team) Selected Based on Designs and Other Appropriate Considerations
- **Winning Team Orders Long Lead-Time Material**

Lead Ship Contract (Cost + Fixed Fee) Awarded to Single Yard or Industry Team

Follow Ships Awarded Under Fixed-Price-Plus-Incentive-Fee Contract

Figure 3. Acquisition Strategy

Those involved in ship acquisition face greater challenges in implementing DoD guidance on acquisition reform than managers for other types of systems. In the case of aircraft, the major companies—Boeing, Lockheed-Martin, McDonnell Douglas, and Northrop Grumman—have commercial sides, so the companies are well versed in commercial practice. By contrast, the major U.S. shipbuilders have virtually no commercial business, so there is no in-house "role model." Nevertheless, acquisition reform has a high potential to improve the outcomes of ship acquisition programs. Progress has been made in the reduction of military specifications and standards, but significant work in this and other areas remains. Therefore, *we believe that the Navy should enthusiastically embrace and implement acquisition reform. Navy shipbuilding*

acquisition personnel should communicate regularly with acquisition personnel for other system types to share experiences as acquisition reform progresses. In turn, OSD oversight should be tailored to the needs and risks of each specific program. Table 5 identifies a number of specific acquisition reform actions that merit consideration for surface ship programs and characterizes their strengths and weaknesses. [Chapter I, Section D]

Table 5. Potential Ship-Related Acquisition Reform Actions

Action	Potential Benefits	Potential Drawbacks
Integrated Product Team	All benefits of concurrent engineering, including lower cost, more producible design, more maintainable design	Team becomes unwieldy, with everyone involved in everything
Overarching Integrated Product Team	Problems surface early and are addressed, Team approach vice adversarial approach	Heavy consumption of time in meetings, subordinates not given sufficient authority to commit their superiors, diffuse accountability
Increased use of commercial specifications and standards in lieu of military specifications	Reduced cost due to increased use of commercial items	Products may not meet military needs
Cost as an independent variable (CAIV)	Lower costs based on cost-performance tradeoffs More maintainable systems Promotes multiple options and creative solutions	Lower-capability systems Requires ability to support cost/performance trade studies Difficult to enforce in sole source environment
Commercial-style competition	Lower prices, due to less time spent in writing detailed proposals Government can appropriate best ideas	Political considerations may not permit high rewards for defense contractors Volatile profit margins make planning more difficult for industry
Full and effective competition	Allows government to negotiate with best companies	May exclude some viable competitors

D. SHIP DESIGN AND PRODUCTION PRACTICES

By taking steps to ensure that ship design and production practices are more closely integrated, both the Navy and the shipyards should receive considerable benefits. Taking account of production considerations during design will enable more efficient construction by improving the yard's ability to plan and schedule work and by helping to

eliminate costly rework. Two approaches appear particularly promising — the Integrated Product and Process Development Team (IPPDT) and the development of build strategies.

Use of the IPPDT concept will better enable ship production, operation, and maintenance considerations to be taken into account in the design phase. As shown in Figure 4, the IPPDT is a multi-disciplinary team that includes designers, builders, maintainers, and operators. Ideally, the IPPDT should include both Navy and industry personnel in order to form a coherent and well-orchestrated design and development team. As the IPPDT process matures, the team should be expanded to include the supplier base and, ultimately, to make the entire Navy acquisition program one large IPPDT that eliminates stove piping and better reflects the fleetwide impact of programs. [Chapter II, Section C]

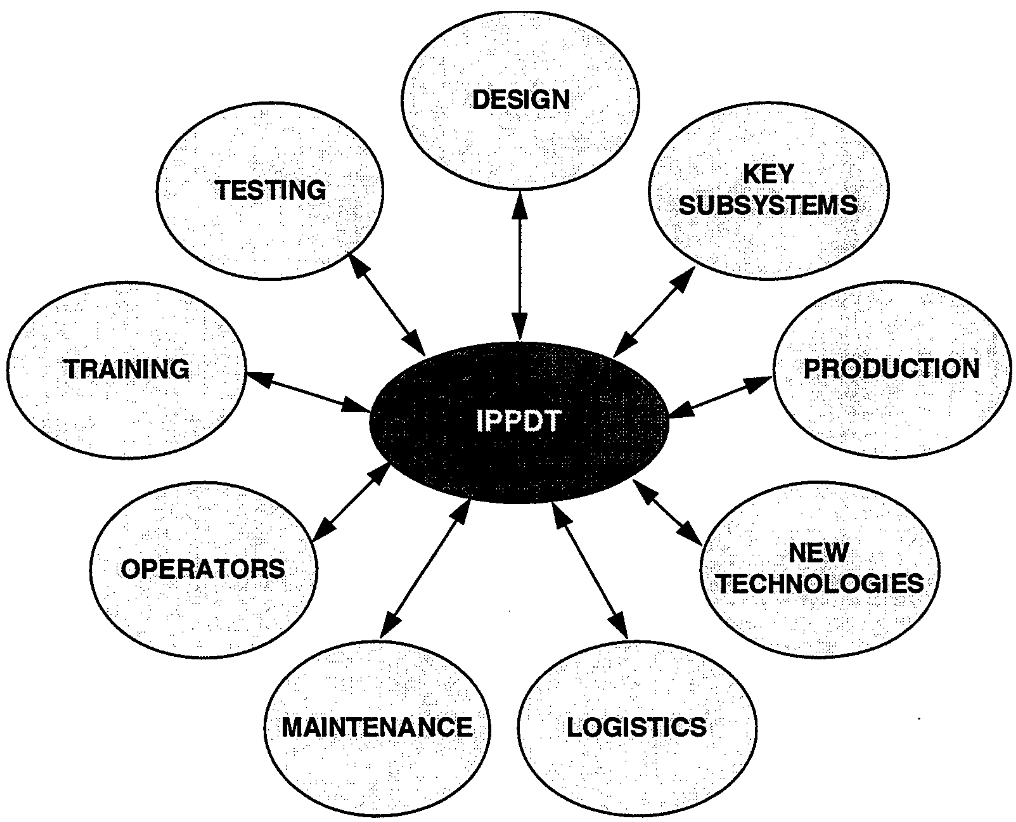


Figure 4. Notional Integrated Product and Process Development Team

Another useful way of incorporating production factors early in ship design is through development and use of a build strategy. As a first step in this direction, the Navy is currently working with several shipyards to develop a generic build strategy that could be used to guide construction of naval vessels at any of the major shipyards. Because the generic strategy would not be optimized for any particular shipyard, it would obviously be less efficient than one structured around the specific capabilities of a given yard. However, by requiring the participating shipyards to identify, describe, and quantify their existing production practices, the generic strategy has already been of benefit. Once the generic strategy is completed, the shipyards can use it as a guide to refine their existing processes or devise a build strategy for a specific construction program. [Chapter II, Section C]

Use of computer-aided tools (see Figure 5) has already improved ship design and production processes in significant ways; the benefits can only increase as the utilization and capabilities of these tools expands. To fully realize these benefits, data standards must be developed and implemented so that design information can be easily and readily exchanged. By standardizing the data exchange requirements for computer-aided tools, design details can be shared among designers, builders, operators, maintainers and suppliers regardless of the particular software or hardware architectures being used. Electronic design libraries for common ship modules (e.g., a "typical" engine room) can be constructed and made broadly available within the shipbuilding community. Development of data standards would also facilitate application of common ship modules across several classes, enable creation of digital product catalogs and use of computer-aided logistics systems (CALS), and make possible simulation-based design (SBD). The Navy's standardization program for product and process data models should be fully supported. [Chapter II, Section E]

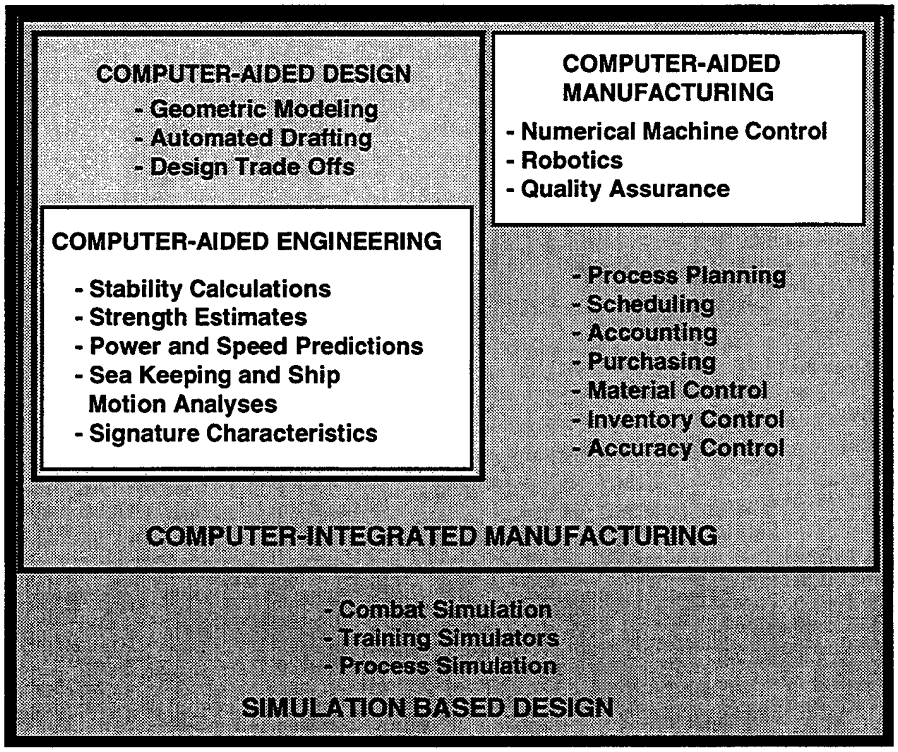


Figure 5. Computer-Aided Tools for Ship Design and Production

To further facilitate ship production, U.S. shipbuilders should fully adopt group technology shipbuilding. This scheme arranges and sequences shipbuilding operations in order to bring the benefits of mass production to the shipyard's high variety, mixed quantity production process. Implementation of group technology shipbuilding requires (1) use of a product-oriented work breakdown structure during the construction process so that work can be organized into packages with equivalent work content (e.g., as measured by the number of labor hours required) and (2) the adoption of a team approach to construction. Cross training of shipyard workers in multiple skills (e.g., welding and painting) is essential to realizing the benefits of group technology shipbuilding. In addition, the production process should be engineered and scheduled so that as much work as possible can be accomplished in shop. Work that cannot be completed in shop should be accomplished on block; work should be done on ship only when absolutely essential. [Chapter III, Section C]

Accuracy control constitutes another key element of group technology shipbuilding. Distinct from quality control, accuracy control denotes use of statistical techniques to monitor, control, and continuously improve design details, planning, and work methods so as to maximize productivity. Processes are measured and quantified so as to enable use of only the degree of precision actually required. *Accuracy control must be integrated into all aspects of design, planning, and production.* Its successful implementation reduces rework, helps control the overall ship production process, and ultimately helps lower ship cost. [Chapter III, Section C]

To improve its management of ship production, the *Navy should consider collocating at least a portion of the program office at the building yard* so as to facilitate interaction between the Navy system commands and the shipyard. Doing so would also relieve the local Supervisor of Shipbuilding (SUPSHIPS) of this burden and enable that organization to concentrate on change order pricing, ensuring compliance with the yard's quality assurance program and monitoring work progress. The *Navy should also reduce the number of contract deliverables required to the minimum needed for efficient management and then allow the yard to submit these electronically* rather than on paper. Every effort should be made to use information already resident in the yard's management system rather than specially formatted and prepared deliverables. The Navy should also investigate ways to reduce the costs associated with requiring use of government-furnished information (GFI) and equipment (GFE). *The Navy should also continue its efforts to devise planning factors and management approaches to better manage the design changes that are an inevitable part of the ship construction process* given the complexity of ship systems and the ship design and construction processes themselves. To the extent possible, changes should be consolidated into block upgrades whenever the ship buy is large enough to make this approach feasible. [Chapter III, Section B]

E. INCREASED CONSTRUCTION OF COMMERCIAL SHIPS

Increasing production of commercial ships within U.S. shipyards will be both a difficult task and one whose success is far from certain. The principal considerations underlying this assessment include the following:

- Over the last 50 years the United States has never had a major presence in the commercial shipbuilding market. Instead, the major U.S. shipyards have concentrated their marketing and production skills on building naval ships for which performance rather than cost is usually the overriding consideration. Marketing organizations and distribution networks will have to be created with completely different orientations and skills, and will require major adjustments in the thinking of emplaced managements and personnel. Such adjustments have proven extremely difficult in other industries.
- The absence of the U. S. industry from international shipbuilding has meant that there is little acquired expertise in the design of commercial oceangoing ships. There is no library of standardized designs that can be readily marketed and easily adapted to changing customer requirements.
- The United States begins with severe disadvantages in commercial shipbuilding technology even when confronted with competitors like Korea or Poland, which lag considerably in most other areas of manufacturing. U.S. shipbuilders will have to shift from naval ships, which require several million labor hours to build, to commercial ships which, if built competitively, must be manufactured for 500,000 to 600,000 labor hours or less. The shipyards will have to develop *ab ovo* skills in computerized commercial ship design, robotized and closely time-phased production processes, modularized mass production techniques adapted to commercial ship production, machinery specialized to shipside production methods, as well as networks of component suppliers and subcontractors skilled in commercial ship needs and closely integrated with shipyards — all while facing experienced incumbents in the industry.
- On the scale of complexity, commercial ship construction is, to a large extent, a steel fabrication and assembly industry whose technology is not difficult to acquire. With the exception of modest numbers of more complex vessels such as refined product tankers, liquid natural gas carriers, and cruise ships, most commercial ship construction requires little of the highly skilled labor needed to assemble modern naval combatants. Construction of tankers and bulk cargo carriers has followed the lowest labor rates, first to Japan, then to Korea, and soon to China and Brazil. U.S. shipyards cannot reasonably hope

to compete for such ships. The only plausible commercial opportunity will be the smaller market of more complicated vessels.

- Commercial ship construction is highly cyclical and characterized by large changes in amplitude. Ships are major investments and highly durable, so that replacement can often be postponed for long periods. The second hand market offers alternatives to newbuilding in periods of financial stringency or uncertainty for shippers. Existing ships can be used more intensively when demand for services rises. And the underlying demand for shipping services from which newbuilding is derived reveals a history of uncertain forecasts. To reestablish their commercial shipbuilding capability, U.S. shipyards will have to make substantial investments. Such investments may, in the medium run, prove burdensome and lead to bankruptcies if the anticipated boom fails to materialize or cannot be sustained. The parent firms that own the yards may be rationally risk-averse and reluctant to commit substantial funds for such purposes, and thereby forego the opportunity to improve altogether.

- The international shipbuilding industry is highly subsidized by nations who have had a long tradition of government participation in one guise or another in their industrial sectors. The United States, in contrast, does not have a tradition of active "industrial policy," even when the only rational adjustment that an industry can make is to shift reduced capacity into newer forms of product within the industry or go out of business entirely. As a consequence, the United States will always be a reluctant and therefore less-skilled player in the game of subsidization and protectionism.

- Mergers and consolidations among the major shipyards with downsizing of capacity and labor force may occur. Mergers could be beneficial by concentrating the reduced Navy demand into a smaller number of viable facilities. Some of these merged yards may be able to enter niche markets in the commercial shipbuilding industry. As a companion activity to naval shipbuilding, such yards could exploit the economies of scale and scope that arise from the joint defense-commercial production. This smaller body of more viable firms would be led to increased partnerships with foreign firms to share technology, designs, suppliers and facilities, thus reducing costs and increasing efficiency.

In the event that downsizing is eventually seen to place the nation's naval shipbuilding capability at risk, then other solutions should be considered. These could include outright payments from the defense budget to a subset of yards whose potential for Navy construction is judged vital to the national interest; the possible purchase of that subset of yards by the government to form a notional government shipyard managed by

private firms; or the annual payment to firms in that subset of contractual amounts as *option demand*, in recognition of the government's right, if necessary, to call upon these yards' capacity to provide such ships, on an agreed contractual basis.

This page intentionally left blank

BIBLIOGRAPHY

1. American Society of Naval Engineers, ASNE Day 1995, Annual Meeting and Exhibition, 16-19 May 1995.
2. Bath Iron Works, Corporate Presentation, November 1994.
3. BDM Federal Inc., *Naval Industrial Base Study*, Final Report, 17 March 1994.
4. Commander Naval Sea Systems Command, *The Strategic Plan of the Naval Sea Systems Command 1995: "Reshaping Our Course ... to the Future,"* 30 March 1995.
5. Department of the Navy, *A Mandate for Change*, Briefing on Navy Acquisition Reform Efforts, 8 January 1995.
6. Kiss, Ron and CDR Ernest Valdes, *DDG 51 Acquisition Study: Preliminary Results*, Business Sensitive, June 1995.
7. Marine Log, Commercial Shipbuilding USA, Second Annual Conference, Washington, D.C., 7-8 December 1994.
8. Marine Log, Commercial Shipbuilding USA, Third Annual Conference, Washington, D.C., 5-6 December 1995.
9. Maritime Administration, *Outlook for the U.S. Shipbuilding and Repair Industry – 1995*, January 1995.
10. Maritime Administration, *National Shipbuilding Initiative*, Presentation to IDA, 26 July 1995.
11. National Research Council Committee on National Needs in Maritime Technology, Shipbuilding Technology and Education, 1995.
12. NATO Specialist Team on Ship Costing, *Ways to Reduce Costs of Ships*, 10 November 1994.
13. President William J. Clinton, *Strengthening America's Shipyards: A Plan for Competing in the International Market*, 1 October 1993.
14. Rost, Ronald F. and Carla E. Tighe, *Shipyard Costs and Capabilities*, CRM 92-13, Center for Naval Analyses, May 1992.
15. Shaffran, Robert, Advanced Research Projects Agency, *MARITECH*, Overview Presentation, 27 June 1995.
16. Shipbuilders Council of America, *The Transition of American Shipyards to Commercial Markets*, Presentation to The Engineers Club of Sparrows Point, 24 February 1994.

17. Society of Naval Architects and Marine Engineers and The Association of Scientists and Engineers, *Naval Ship Design: Setting Course for the 21st Century*, Arlington, Virginia, 25 February 1992.

18. Society of Naval Architects and Marine Engineers, 1995 Ship Production Symposium, Seattle, Washington, 25-27 January 1995.

19. Society of Naval Architects and Marine Engineers, Annual Meeting Technical Sessions, Washington, D.C., 5-6 October 1995.

20. Society of Naval Architects and Marine Engineers, 1996 Ship Production Symposium, San Diego, California, 14-16 February 1996.

21. Stewart, John M. and Arthur J. Haskell, *Can Technology Revitalize Our Shipbuilding Industry?,* SNAME Annual Meeting, 5 October 1995.

Part 2

ANALYSIS

I. SHIP ACQUISITION STRATEGY

The government can pursue several different strategies in acquiring ships. The government can design the ship, then hand the design to a contractor for construction. Alternatively, the government can describe its needs, then ask a contractor to design the ship. The government can choose to prototype major components, or not. The government decides what type of contract to award and what behavior, if any, to incentivize. All of those decisions influence the quality of the ship, as well as the degree to which the program adheres to its planned cost and schedule.

Since the late 1960s, the government has pursued a variety of acquisition management strategies—some highly successful, others less so. Given the complexity of the process, it is often impossible to discern a cause and effect relationship regardless of a program's success or failure. This conundrum, however, should not dissuade us from examining the results of past program to determine the lessons they hold for the future. Today, it is more important than ever that programs to acquire ships be carefully designed and managed. Both quantitative and qualitative experience can be helpful to the government in developing suitable management strategies.

In the first section of the chapter, we analyze a set of 17 historical ship acquisition programs to determine the extent to which acquisition strategy affected schedule and cost. The management strategies pursued in each program are quantitatively related to the programs' outcomes. (The program histories provided in Appendix A add detail and anecdote to the quantitative analysis.) The next section describes the major historical eras in ship acquisition and discusses a variety of acquisition strategy issues. The final section summarizes the study's findings related to acquisition strategy.

A. METHODS AND HISTORICAL PROFILE

1. Ship Programs Examined and Data Sources

The ship programs covered in this analysis are listed in Table 6; additional details are reported in Appendix A. Data for these programs were obtained from Selected

Acquisition Reports and information supplied by the Navy Center for Cost Analysis, supplemented with information from program offices.

Table 6. Ship Programs Examined

Program	Class	Type	New Design or Modification of Existing Design	Number Built or Planned	Ship Builder
AOE 6	Supply	Combat support	New	4	NASSCO
CG 47	Ticonderoga	Surface combatant	Mod of DD 963	27	Bath Iron Works, Litton/Ingalls
CVN 68 to CVN 70	Nimitz	Aircraft carrier	New	3	Newport News Shipbuilding
CVN 71 to CVN 73	Nimitz	Aircraft carrier	Mod	3	Newport News Shipbuilding
CVN 74 to CVN 76	Nimitz	Aircraft carrier	Mod	3	Newport News Shipbuilding
DD 963	Spruance	Surface combatant	New	31	Litton/Ingalls
DDG 51	Arleigh Burke	Surface combatant	New	57[a]	Bath Iron Works, Litton/Ingalls
FFG 7	Oliver Hazard Perry	Surface combatant	New	51	Bath Iron Works, Todd/ Seattle, Todd/San Pedro
LCAC	N/A	Transport	New	91	Bell Aerospace, Lockheed Shipbuilding
LHA 1	Tarawa	Amphibious warfare	New	5[b]	Litton/Ingalls
LHD 1	Wasp	Amphibious warfare	Mod of LHA	7	Litton/Ingalls
LSD 41	Whidbey Island	Amphibious warfare	Mod of LSD 36	8	Lockheed Shipbuilding, Avondale
LSD 41CV	Harpers Ferry	Amphibious warfare	Mod of LSD 41	4	Avondale
MCM 1	Avenger	Mine countermeasures	New	14	Peterson Builder, Marinette Marine Corp.
MHC 51	Osprey	Mine countermeasures	Mod of LERICI Class	12	Intermarine USA, Avondale
SURTASS/ T-AGOS	Stalwart	Ocean surveillance	New	12	Tacoma Boat Building, Halter Marine
TAO 187	Henry J. Kaiser	Replenishment oiler	New	16	Avondale, Penn Shpbldg/ Tampa Shpyd

N/A = Not Available

[a] DDG 51 class is still in production

[b] Nine LHAs were included in the original contract. The number was reduced to 5 during contract renegotiation.

Three of the 17 ship classes—the CVN 74-76, the DDG 51, and the LHD 1—are still in production. The earliest program—the LHA 1—began full-scale development in 1969, started production in 1971 and finished production in FY1981. The dates that each of the systems started development and production, along with the initial operational capability dates and projected production end dates, are shown in Table 7.

Table 7. Development and Production Start and End Dates for Ship Programs

Program	Class	Full Scale Development Start	Production Start	IOC	Production End
AOE 6	Supply	10/84	3/86	5/95	9/93
CVN 68-70	Nimitz	10/66	10/67	2/83	2/83
CVN 71-73	Nimitz	9/80	9/80	N/A	9/93
CVN 74-76	Nimitz	10/88	10/88	6/96	9/03
CG 47	Ticonderoga	3/78	3/78	1/83	FY88
DD 963	Spruance	6/70	6/72	6/77	2/83
DDG 51	Arleigh Burke	12/83	4/85	2/93	FY04
FFG 7	Oliver Hazard Perry	10/72	10/73	3/79	9/84
LCAC		2/80	6/81	2/87	9/89
LHA 1	Tarawa	4/69	1/71	5/77	FY81
LHD 1	Wasp	7/82	2/84	11/90	FY00
LSD 41	Whidbey Island	11/78	1/81	2/86	FY86
LSD 41CV	Harpers Ferry	12/87	11/89	N/A	FY93
MCM 1	Avenger	8/81	6/83	8/87	FY90
MHC 51	Osprey	12/86	2/89	12/92	FY93
SURTASS/T-AGOS	Stalwart	10/74	9/80	9/84	FY90
T-AGOS 23	Stalwart	6/87	3/91	5/99	FY00
TAO 187	Henry J. Kaiser	2/81	11/82	2/87	FY89

Note: N/A means that data were either not available or insufficient.

Current estimates of how much the ship production costs would be for the quantities originally planned for at the time of the development estimates were calculated using price improvement curves.

Information on the acquisition program initiatives applied to each of the programs was obtained from Navy, OSD, and industry sources. The program effectiveness measures were then compared on the basis of the particular acquisition program initiatives applied to determine the initiatives' effectiveness. The comparisons were made using statistical tests to determine whether there were any statistically significant differences between the sample of programs to which a particular acquisition initiative was applied and the sample of programs to which the initiative was not applied.

B. SHIP PROGRAM OUTCOMES

1. Distinguishing Features of Ship Acquisition Programs and Implications

Estimates of development, military construction, and production costs for fifteen different ship programs are shown in Table 8. These estimates are based on data from the December 1994 SARs.

Table 8. Current Estimates of Ship Program Costs (Millions of FY 1996 Dollars)

Program	Production Units — Original Plan	Production Units — Actual or Current Plan	Development Cost	Production Cost[a]	Production Average Unit Cost	Total Program Cost[b]
AOE 6 Supply	7	4	43	2594	648	2636
CG 47 Ticonderoga Class	16	27	146	29183	1081	29326
CVN 68-CVN 70	3	3	0	11131	3710	19221
CVN 71-CVN 73	3	3	2	11491	3830	11494
CVN 74-CVN 76	3	3	40	12435	4145	12475
DD 963 Spruance Class	30	31	146	14668	473	14814
DDG 51 Arleigh Burke Class	18	57	2737	51715	907	54452
FFG 7 Oliver Hazard Perry Class	50	51	65	15134	297	15199
LCAC	60	91	49	2768	30	2817
LHA 1 Tarawa Class	9	5	88	5998	1200	6086
LHD 1 Wasp Class	2	6	66	9698	1616	9765
LSD 41 Whidbey Island Class	12	8	21	3226	403	3247
LSD 41 CV Harpers Ferry Class	8	6	16	1308	218	1325
MCM 1 Avenger	14	14	33	2301	164	2334
MHC 51 Osprey	12	12	21	1594	133	1614
SURTASS/ T-AGOS Stalwart Class	12	18	286	681	54	967
TAO 187 Henry J. Kaiser Class	17	16	23	3757	235	3779

Note: N/A means that data were either not available or insufficient.
[a] Government current estimate from 1994 SAR
[b] Excludes military construction cost

There are several features which distinguish the ship acquisition programs from the other acquisition programs. The first is that there are generally low numbers of units

produced with very high unit costs. The greatest quantity to be produced in any of the ship programs is 91, and the median is 10. [The median of the average unit production costs for the ship programs is over $600 million, and the highest of the average unit production costs is over $6 billion.]

The second distinguishing feature of the ship acquisition programs is that development costs are a low proportion of total program costs. Across the 17 programs for which total cost data are available, the mean percentage of development costs to total costs is 2.8 percent, and the median is an even lower, 1.0 percent. There are three basic reasons for these low percentages. First, the Navy takes a more direct role in early development than do the other services, and these costs may not be fully accounted for in the development line item. Second, much of what the rest of the defense industry refers to as development costs are included in Navy production costs; in particular, the costs of detailed design are typically funded by Ship Construction Navy (SCN) appropriations rather than Navy development appropriations. The third reason is complexity—ship production costs include the costs not only of the ship and its associated propulsion system (except for certain nuclear powerplant costs) and auxiliary equipments, but also the costs of the combat systems with which the ship is equipped.

According to a recent study of modern surface combatants [Rains, 1994], the cost of DDG 51 class ships (approximately $1 billion each) can be broken down as shown in Figure 6. To the extent that combat systems represent a known cost to the Navy, their large contribution to total ship cost helps explain the low cost growth (actual versus planned cost) in Navy ships.

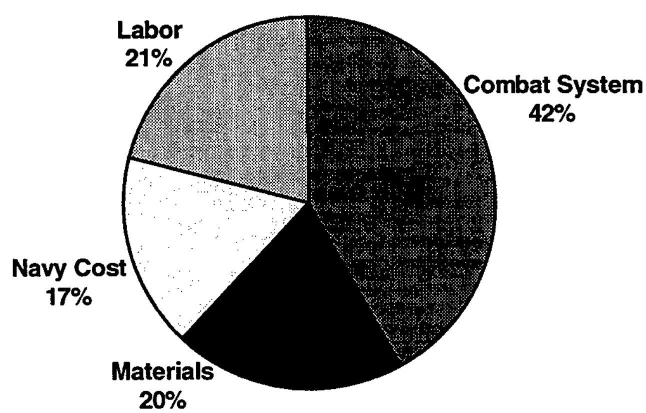


Figure 6. Cost Breakdown for Modern Surface Combatant

The third distinguishing feature of the ship acquisition programs is that they have been taking place at a time of great overcapacity in the U.S. shipbuilding industry. The numbers of merchant ships over 1,000 gross tons produced annually by U.S. shipyards for both domestic and foreign ship owners have declined since 1949 because of lower costs for foreign ship construction and a recurrent boom and bust cycle of overcapacity in available merchant shipping tonnage world-wide. Thus, DoD is the only major customer for the U.S. shipyards. As a result, there has been short-run pressure on shipyards to compete with lower prices to DoD. If a shipyard is unable to produce the ship at the low price it bid, DoD must either provide the additional funds required or lose its entire investment. In the longer run, shipyards will go out of business, either voluntarily or involuntarily as in the cases of Lockheed Shipbuilding and Construction, Pennsylvania Shipbuilding, and Todd Shipyards, among others. A smaller number of competitors in the future may result in higher production costs for naval ships.

The fourth distinguishing feature of the ship acquisition programs is the high cost of adapting equipment to operate in the stringent marine operating environment. The two primary environmental problems are corrosion from saltwater and humid sea air, and the pounding and shocks to the hull of the ship as it moves through the sea. As a result, commercial grade equipment is rarely adapted to maritime use. Further, the costs of Mil Spec equipment developed for the maritime environment inhibit its use elsewhere. As a result, there is an incentive to use expensive combat systems developed for a maritime environment across as many Navy programs as possible. This economizes on both development and production costs. It also implies that cost growth should be lower for ship programs because of the extensive use of combat systems across multiple ship classes. Examples of this commonality for the ship programs examined in this analysis are provided in Table 9.

Table 9. Commonality of Subsystems Among Ship Classes

Subsystems	Type	Manufacturer	CG 47	DD 963	DDG 51	FFG 7	LHA 1	LHD 1	LSD 41
LM 2500	Gas Turbine	General Electric	X	X	X	X	—	—	—
AN/SLQ-32	ECM System	Raytheon	X	X	X	X	X	X	X
AN/SPG-60	Gun Tracking Radar	Lockheed	—	X	—	—	X	—	—
AN/SPG-62	Missile Fire Control Radar	Raytheon/RCA	X	—	X	—	—	—	—
AN/SPQ-91	Fire Control Radar	Lockheed	X	—	—	—	X	—	—
AN/SPS-40	Air Search Radar	Lockheed	—	X	—	—	X	—	—
AN/SPS-49	Air Search Radar	Raytheon	X	X	—	X	—	X	X
AN/SPS-52	Air Search Radar	Hughes	—	—	—	—	X	X	—
AN/SPS-55	Surface Search Radar	ISC Cardion	X	X	—	X	—	—	—
AN/SPS-64	Navigation Radar	Raytheon	X	X	X	—	X	X	X
AN/SPS-67	Surface Search Radar	Norden	—	—	X	—	X	X	X
AN/SQQ-89	Towed Array Sonar	Gould	X	X	X	X	—	—	—
AN/SQS-53B/C	Hull Mounted Sonar	General Electric/Hughes	X	X	X	—	—	—	—
AN/SQS-53C	Hull Mounted Sonar	General Electric	X	X	—	X	—	—	—
MK 29	Missile Launch System	Raytheon	—	X	—	—	—	X	—
MK 32	Torpedo Launch System	—	X	X	—	X	—	—	—
MK 41	Missile Launch System	FMC	X	X	X	—	—	—	—
MK 15	Phalanx Gun System	General Dynamics	X	X	X	X	X	X	X
5"/54 MK 45	Gun	FMC	X	X	X	—	X	—	—
MK 7 AEGIS	Weapon Control System	General Electric	X	—	X	—	—	—	—
MK 116	Underwater Fire Control System	Singer Librascope	X	X	—	—	—	—	—
	Navy Tactical Data System	Hughes	X	X	X	X	—	—	—

2. Outcomes of Ship Acquisition Programs

Acquisition program outcomes for the 17 ship programs examined are shown in Table 10. With reference to the column headings used in the table, *cost growth* is defined as the percentage by which actual cost exceeds estimated cost. (Negative growth is, of course, possible, if the actual turns out to be less than the estimate.) In development, actual cost is measured from the beginning of development to the end of development of the first version of the system. In production, actual cost is adjusted for quantity change, by means of a price improvement curve. Production cost growth is measured based on the quantity planned at Milestone II. *Quantity growth* is defined as the percentage by which actual quantity exceeds planned quantity, while schedule growth is defined as the percentage by which the actual schedule exceeds the planned schedule. The development schedule is defined as the number of months from Milestone II to IOC, while the production schedule is defined as the number of months from Milestone III to the year when the last quantity is indicated in the funding summary in the SAR. (Ideally, we would have measured the end of production as the last delivery, but it is difficult to obtain this information for all ships. Moreover, for programs that are still in production, the year when the last quantity is planned is easier to obtain.) *Production schedule growth* and *stretch* are two different ways at looking at production schedule. Production schedule growth measures actual vs. planned schedule even though quantity may have changed. Stretch measures schedule growth in terms of the time required to produce the originally-planned quantity.

These outcome measures appear to be quite different from the outcome measures for other types of weapon systems as determined in a prior IDA study. [Tyson, *et al*, 1992] In that study, the programs exhibiting the highest total program cost growth were tactical munitions (103 percent) and vehicles (96 percent). The lowest cost growth was exhibited by ships (15 percent), although the population of programs was different from the current study. The earlier study included many of the surface ships examined here as well as the SSN 21 and the SSN 688. It did not, however, include AOE 6, aircraft carriers, LCAC, MCM 1, MHC 51, or T-AGOS.

In the current study total cost growth and production cost growth were much less for the ship programs, while development cost growth was somewhat less. Development schedule growth was much less for the ship programs, but production schedule growth was only somewhat less. Production quantity growth turned out to be much higher for the

expanded set of programs, primarily because some of the initial estimates of production quantities were for minimal numbers.

Table 10. Outcome Measures for Ship Programs (Percent)

Program	Development Schedule Growth	Development Cost Growth	Production Cost Growth	Production Quantity Growth[a]	Production Schedule Growth	Stretch	Total Program Cost Growth
AEO 6 Supply	55	8	30	-48	-12	54	30
CG 47 Ticonderoga Class	10	23	-4	69	-46	-33	-4
CVN 68	3	N/A	17	0	3	3	17
CVN 71	-3	7	1	0	8	8	1
CVN 74	N/A	-20	8	0	73	73	8
DD 963 Spruance Class	40	6	23	3	78	72	23
DDG 51 Arleigh Burke Class	34	133	-1	217	131	-10	-14
FFG 7 Oliver Hazard Perry Class	35	43	59	2	-3	-12	59
LCAC	6	56	28	52	57	57	29
LHA 1 Tarawa Class	56	0	51	-44	142	323	50
LHD 1 Wasp Class	8	9	-9	133	249	-3	-9
LSD 41 Whidbey Island Class	4	11	-10	-33	-26	10	-10
LSD 41 CV Harpers Ferry Class	10	-28	-5	-20	21	50	-5
MCM 1 Avenger	0	0	4	0	-13	-13	4
MHC 51 Osprey	0	8	1	0	0	0	1
SURTASS Class	54	239	64	50	189	-14	85
T-AGOS	25	-5	18	-40	46	77	20
TAO 187 Henry J. Kaiser Class	4	-2	6	-6	-13	-7	6

Note: N/A means that data were either not available or insufficient

[a] The baseline for quantity growth is the Milestone II estimate. For ships, such an estimate may be artificially low, particularly for programs that had their Milestone II during a time (like the 1980s) when planned quantities had to be fully funded.

3. Effects of Acquisition Initiatives on Ship Program Outcome Measures

The major acquisition initiatives that were applied to these ship programs are identified in Table 11. The specific initiatives examined are defined briefly here: *Subsystem prototyping* has been used in ship subsystems to reduce technical risk by building and testing detailed pieces of hardware early. *Dual sourcing* involves two or

more sources in production, by our definition, rather than the competition of companies for full scale development (FSD) or production contracts, which is fairly routine. Dual sourcing of major systems often requires a considerable investment in technology transfer and qualification. *Design-to-cost* (DTC) was widely practiced in the 1970s. It involves setting a cost goal very early on, similarly to the way a performance goal is set. Progress toward meeting the cost goal is reported periodically. *Multi-year procurement* (MYP) involves committing the government to a procurement and funding plan for several years, in the hope that contractors will be able to produce at lower cost with a stable plan. *Fixed-price development* (FPD) evolved in the Navy in the early 1980s as a way of forcing contractors to share some of the risks in development. We also consider the historical experience of *total package procurement* (TPP), which forced the contractor to share the risk of both development and production by specifying a fixed price for at least the first production lot before development. *Contract incentives* are frequently used to induce the contractor to reduce costs or to engage in other behavior beneficial to the government. Incentive fee contracts typically involve a cost target, and the contractor splits savings or additional costs with the government based on actual costs. Award fee contracts are more complex; typically, a list of criteria for the program manager or a review board is used to determine the fee awarded.

To determine if application of these initiatives has had a statistically significant effect on cost or schedule outcome, we examined Pearson correlation coefficients[1] for the zero-one (0, 1) variables representing the acquisition initiatives and intermediate outcome measures with total program cost growth (TPCG). There were 8 significant correlations:

---

1 The Pearson correlation coefficient ρ is the statistic used most often in correlation analysis. The correlation coefficient measures the strength of the linear relationship between two variables, in our case total cost growth and the policy variables. When $\rho = 1$ or -1, there is a perfect linear relationship, positive or negative respectively, between the variables. When $\rho = 0$, the two variables are uncorrelated and (if we assume that their distribution is bivariate normal) independent. The definition of ρ and a computational formula can be found in any standard text such as [Freund, 1971] or [Kmenta, 1986]. The significance test for the correlation coefficient tests the null hypothesis that $\rho = 0$, using the normal distribution. We used a significance level of .10 as sufficient to reject the null hypothesis.

Weighted regression is used as a remedy for heteroskedasticity, or non-constant variation of a residual across the values of another variable. From prior studies, we have noted that there are some differences between large and small dollar-value programs in terms of the effectiveness of initiatives. Weighted regression allows the large programs to have greater influence in the regressions.

Table 11. Acquisition Initiatives Applied in Ship Programs

Ship Program	Subsystem Prototype Included	Dual-Sourcing		Other Acquisition Initiatives				Contract Incentives	
		FSD	Production	DTC	MYP	FPD	TPP	FSD	Production
AOE 6	0	0	0	0	0	1	1	1	1
CG 47	1	0	1	1	0	0	0	1	1
CVN 68	0	N/A	0	0	0	N/A	0	N/A	1
CVN 71	0	0	0	0	0	0	0	0	1
CVN 73	0	0	0	0	0	0	0	0	1
DD 963	1	0	0	0	1	0	1	1	1
DDG 51	0	0	1	1	0	0	0	N/A	1
FFG 7	1	1	1	1	0	0	0	1	1
LCAC	1	1	1	1	1	0	0	N/A	1
LHA 1	0	0	0	N/A	0	0	1	1	1
LHD 1	0	0	1	1	0	0	0	1	1
LSD 41	0	1	1	1	0	0	0	1	1
LSD 41 Cargo	0	0	1	1	1	0	0	0	1
MCM 1	0	1	1	0	N/A	N/A	0	N/A	1
MHC 51	0	0	1	0	0	N/A	0	N/A	1
SURTASS-T/AGOS	1	0	0	1	0	0	1	0	1
T-AGOS 23	1	0	0	0	N/A	0	0	0	1
TAO 187	0	0	1	0	0	1	0	1	1

Note: N/A means that data were either not available or insufficient

1. Development schedule growth was positively correlated with TPCG. This makes sense: programs that take longer than expected between Milestone II and IOC are likely to have cost growth.
2. Development cost growth, positive. Programs that have cost problems in development are likely to have problems in production as well. [2]
3. Total schedule growth, positive. Schedule problems in both development and production lead to higher TPCG.
4. Modification programs, negative. As expected, programs that build on the experiences of other systems tend to have lower TPCG.
5. Subsystem prototyping, positive. Programs that prototype sub-systems tend to have higher cost growth. This finding is puzzling and contradicts other results [4]. It may be that, for ships, the strategy of commonality is more

---

[2] The correlation between production cost growth and TPCG is also strongly positive, but this was not reported as a research finding, because it is essentially tautological. The fact that DCG and TPCG are correlated is meaningful, since development money represents a relatively small part of total program spending.

effective than prototyping, or that negative system-wide factors overwhelm the impact of prototyping.

6. Dual sourcing in production, negative. Programs that used dual sourcing in production had lower TPCG than other programs.

7. Total package procurement, positive. Programs that used total package procurement had higher TPCG than other programs.

8. Programs with late baselines, negative. A variable called LAG was created to measure the number of months past Milestone II that the baseline was established. The results indicate that, as expected, programs that established their baselines late in the program (when better cost information should be available) had lower cost growth.[3]

There may be some lessons that are particularly important for larger programs. In order to test for these effects, we performed weighted regression analysis, using TPCG as the dependent variable. Results obtained were similar to those reported above, with the following five exceptions:

1. There was no significant relationship between TPCG and development cost growth.

2. There was no significant relationship between TPCG and prototyping.

3. There was no significant relationship between TPCG and dual sourcing in production.

4. In addition to the significant relationship between TPCG and total schedule growth, there was also a significant positive relationship between TPCG and production stretch.

5. There was a significant negative relationship between TPCG and production quantity growth. Programs that buy more ships than planned tend to have less cost growth. Of course, it is possible that the causality here is reversed. Programs with lower cost growth can be viewed as good buys, therefore, the government increases quantity.

---

3 To correct for the late baseline bias, we developed an alternative measure, TPCG2. The measure was constructed by adding 0.004618 to the TPCG measure for each month that the baseline was late, a figure based on a regression of LAG and TPCG. The results were similar. The only major difference was that dual sourcing in production was no longer significantly related to TPCG.

C. HISTORICAL AND CURRENT ACQUISITION INITIATIVES

1. Historical Acquisition Initiatives

This section discusses the history of U.S. Government's surface ship acquisition strategy since the end of World War II, and is based, for the most part, on information reported in [Tibbitts and Keane, 1995], [Tyson, et al, 1992], and [Nelson and Tyson, 1987].

The Navy has experimented with several approaches to ship acquisition since 1945. In the 1950s, the Navy designed the ship almost completely. There were separate Preliminary Design and Contract Design organizations within the Navy. Construction was done at both government and contractor shipyards.

In the 1960s, the Total Package Procurement initiative became widespread throughout DoD. This approach was a radical departure for military shipbuilding in that private shipbuilders designed the ships rather than the government. Also during the 1960s, the Navy stopped new construction in government shipyards.

In the 1970s, the large claims which developed for several Total Package Procurements, along with the desire for better attention to cost-performance tradeoffs, led to the Design to Cost initiative. All major systems (not just ships) were required to establish a DTC goal and to work toward that goal. The Navy also re-established its central design organization and assumed more responsibility for ship design.

In the 1980s, the Reagan buildup provided ample funds for shipbuilding, including the goal of the 600-ship Navy. However, with the increased funds came heightened Congressional concern about fraud, waste, and abuse and a mandate for competition. A competition advocate was designated for each military service. For a while, development contracts for ships were fixed-price; thus shipbuilders assumed more risk. Dual sourcing for ships became the regular order of the day. Whether or not dual sourcing was a successful cost saving strategy is open to question. It probably was beneficial from an industrial base standpoint. Despite increased shipbuilder participation in the design process, the strategy of fixed-price development was not successful.

An important feature of acquisition in the 1990s is an invigorated Joint Requirements Oversight Council. The Council, chaired by the Vice Chairman of the Joint Chiefs of Staff, has initiated a Joint Warfare Capability Assessment process that could identify increased opportunities for jointness.

By the 1990s, with the end of the Cold War and decreasing appetite for large programs, there was a desire to reform acquisition in conformance with commercial practice with the expectation that this would hold down costs. In the next section, the current initiatives being implemented under the broad heading of acquisition reform are discussed.

2. Acquisition Reform in the 1990s

The Department of Defense is currently attempting to increase use of best commercial practice in DoD system acquisitions through the Acquisition Reform program. In the Secretary of Defense's February 1994 memorandum, "Acquisition Reform—A Mandate for Change" [Perry, 1994], the blueprint for acquisition reform is laid out. In the process of implementing that guidance, DoD is making substantial changes in both government oversight of contractors and OSD oversight of the military services. A key element of the strategy is the use of commercial products and processes in those applications which do not demand the increased cost and performance of Mil Spec material. Another element is a move to reduce non-value-added work, especially in the area of oversight and review. The concepts of acquisition reform and their implementation in ship acquisition are discussed below.

a. Changes in Government Oversight of Contractors

Acquisition reform has a high potential to improve the outcomes of ship acquisition programs. However, those involved in ship acquisition face greater challenges than managers for other types of systems. One of the key organizing principles of acquisition reform is for DoD to behave more like a commercial customer. In addition, DoD wants to encourage more commercial firms to work with the government. In the case of aircraft, the major aircraft companies—McDonnell Douglas, Northrop Grumman, and others—have commercial sides, so their goal is for the government side to be able to function as efficiently as the commercial side of the firm. By contrast, in shipbuilding, the major shipbuilders have virtually no commercial business, so there is no in-house "role model." Moreover, in a downsizing environment, overhead functions might be viewed as profit centers.

Nevertheless, several acquisition reform concepts are being implemented in shipbuilding today. The Navy appears committed to implementing changes in the way business is done.

Federal Acquisition Streamlining Act of 1994 (FASA). Congress has enacted the Federal Acquisition Streamlining Act of 1994. Some reforms in this act include:

- An increased dollar threshold (now $100,000) for using simplified small purchase procedures.
- A performance-based incentivized approach to managing acquisition programs. DoD must approve cost, schedule, and performance goals for each major program and assess whether or not the goals are being achieved.
- Emphasis on streamlining the acquisition process and greater reliance on commercial products and processes.

Integrated Product and Process Development and Integrated Product Teams. Integrated Product Teams (IPTs) are the implementing personnel for the concept of Integrated Product and Process Development (IPPD). The foundation for IPTs involves the related concept of Concurrent Engineering.

The Concurrent Engineering concept originated in industry as a means to enable consideration of all aspects of the life cycle in the early stages of the process. U.S. manufacturers, particularly in the auto industry, faced competition from Japanese manufacturers in terms of the time and money it takes to design a new product and bring it to market. Rather than "throwing the design over the wall" and expecting manufacturers to be able to produce it easily, concurrent engineering advocated the involvement of manufacturers in the design process.

The IPPD concept extends this notion by advocating that a good product requires a good process for designing, developing, producing, and maintaining it. IPTs are multi-disciplinary teams who are involved in the process from the very beginning. Rather than inspecting for quality, quality should be built in from the beginning. Secretary Perry ordered that:

> "Once a contractor has demonstrated a system of stable, compliant processes leading to performance as contracted, the Government shall rely almost exclusively on contractor self-governance, rather than Government inspectors, auditors, and compliance monitors, to ensure that these processes continue to result in a system producing goods and services which meet contract terms and conditions." [Perry, 1995]

Regardless of the type of IPT, the defining factor is the presence of the widest possible set of stakeholders—in many cases involving both government and industry, and certainly involving personnel expert in all phases of the life cycle of the ship.

Design IPTs with shipbuilder participation have enormous potential. Among the benefits are early adoption of a top-level build strategy that can facilitate modern ship construction practices such as zonal architecture, preoutfitting, pretesting, process flow lanes, and modular construction. [Tibbitts and Keane, 1995]

The CVN 76 design, for example, was done with participation from NAVSEA, NAVAIR, Newport News, Warfare Centers, and design agents. In the LPD 17 program, a notional build strategy was developed during preliminary design. The design team was collocated at the time of feasibility studies rather than just for the preliminary or contract design phases. This was driven by the need to develop and assess over a dozen alternative ship concepts. The CVN 76 was also the first ship designed under the revised 5000-series regulations which emphasize the importance of Cost and Operational Effectiveness Analysis (COEA). The building process was simulated in a "virtual shipyard" to allow the designers to address producibility from the very beginning. Among the key benefits were decks and bulkheads aligned for modular construction, a highly producible hull form, a reduced number of types and sizes of material, and increased standardization and commonality.

Reduction of Specifications and Standards. DoD has directed that military specifications and standards become the exception rather than the rule. Performance specifications and commercial standards are to be the primary vehicle for making requirements. In the LPD 17, the number of references to specifications and standards has been reduced from over 1450 to approximately 300. [Tibbitts and Keane, 1995]

Quality Function Deployment. Fleet participation is a key part of the ship acquisition process. Quality Function Deployment (QFD) is a "visual, connective process devised by a Japanese shipyard and effectively used by the Japanese auto industry for better translating customer desires and deploying them throughout all functions." [Tibbitts and Keane, 1995] QFD is a process for translating customer requirements into design requirements. Engineers think about technology, while customers think about uses of the product.

QFD has been applied by the Joint Advanced Strike Technology (JAST) aircraft program to develop ultimate platform attributes based on customer objectives. NAVSEA has used QFD to relate research and development for the future surface combatant and the future aircraft carrier to prioritized fleet needs.

b. Changes in OSD Oversight of the Military Services

Overarching Integrated Product Teams. As previously mentioned, IPTs are the implementing personnel for the concept of Integrated Product and Process Development. In April 1995, Secretary Perry directed "an immediate and fundamental change in the role of OSD and Component staff organizations currently performing oversight and review of acquisition programs." An Overarching IPT is the new vehicle for OSD oversight of the military services' acquisition process. [Perry, 1995] Rather than centering oversight on a finite set of review meetings, staff in charge of oversight are part of the team from the beginning and are kept informed all along. If oversight staff raise an issue, it is resolved immediately, usually by action or explanation from the program staff. If disagreements cannot be resolved at the staff level, the issue is escalated to progressively higher levels until agreement is reached. In this environment, there should be no surprises, and the formal review meetings are often canceled, because there are no outstanding issues. This process is just beginning to be implemented, so it will take some time to see its effects.

Oversight Reform. In April 1995, Secretary Perry emphasized the importance of tailoring acquisition requirements to the needs and risk of each individual program. There should be no minimum set of documents other than those required by statute. To the maximum extent practicable, applicable documents should be incorporated into a Single Acquisition Master Plan (SAMP). There has also been some consolidation of briefings, so that program managers have to spend less time justifying their programs both within the Navy and to OSD.

Revision of DoD 5000 Series. The DoD 5000 series of regulations is currently being revised to reflect the new environment of acquisition reform. The new version of DoD Directive 5000.1 is designed to give the guiding principles of acquisition management. The new version of DoD Instruction 5000.2 describes the mandatory procedures for major acquisition programs. The objectives of the rewrite include:

- Incorporate new laws, policies, procedures and set the stage for cultural change via the IPT process. While the old 5000 series centralized acquisition policy and practice, the new series is designed to streamline and clarify centralized policy but greatly decentralize acquisition practice.
- Clarify and streamline mandatory guidance and facilitate use of professional judgment by program personnel. Acquisition officials had observed confusion about which parts of the regulations are mandatory and which are discretionary, and for what kinds of programs. Regulations that were

mandatory only for major programs have sometimes been interpreted as mandatory for all. The rewritten version is intended to clarify this point.

- Integrate 5000 and 8120 series guidance. (The 8120 series governs the acquisition of automated information systems.)
- Establish an "on-line" deskbook version. In addition to serving as a reference source for the regulations, the deskbook will facilitate interchange among program IPTs and across programs.

After a comment period, it is expected that the new regulations will be promulgated through the Acquisition Deskbook.

c. Potential Changes for the Future

Competition Standards. In shipbuilding and elsewhere, there has been much discussion of changing the requirement for "full and open" competition to a requirement for "full and effective" competition. Full and effective competition would allow the government to act more like a commercial customer in that it could exclude obviously non-competitive bidders early.

Protests can create significant delays in programs. There is no incentive for a contractor not to protest an unfavorable award, since the costs of protests are allowable overhead. DoD wins the vast majority of the protests, but the costs remain.

Pricing Policy. In the commercial world, normal practice is that half of the price is paid at the beginning and half on delivery. DoD is not allowed to do this without permission. Such a practice could limit the yards' need for credit. It might also have the beneficial effect of enhancing a long-term partnership between government and industry.

D. FUTURE ACQUISITION ENVIRONMENT AND ISSUES

1. Military Requirements and Timing of Procurement

Over the next 15-25 years, ship programs now in place will redefine the Navy fleet. Current shipbuilding programs, their status and their anticipated construction contract award dates are summarized in Table 12.

Table 12. New Ship Programs

Program	Program Name	Status	Planned Construction Contract Award Date
Attack submarine	NSSN	Phase I (Post Milestone 0)	FY 1998
Landing dock ship	LPD 17	Phase I (Post Milestone 0)	FY 1998
Dry cargo ship	ADC(X)	Phase I (Post Milestone 0)	FY 2000
Surface combatant	SC 21	Phase I (Post Milestone 0)	FY 2003
Major amphibious ship	LHX	Pre-Milestone 0	FY 2005
Aircraft carrier	CVX	Pre-Milestone 0	FY 2006

Source: [Tibbitts and Keane, 1995]

Three major design projects, the future aircraft carrier, the major auxiliary ship ADC(X), and the surface combatant for the 21st century (SC 21) provide opportunities to continue process improvements established by the CVN 76 and LPD 17 designs.

The LPD 17 program is not far enough along to be included in the analysis of acquisition outcomes, but we can provide a brief discussion of the ship's features and acquisition strategy. The LPD 17 is a new amphibious transport dock assault ship. "A notional build strategy was developed during preliminary design, keyed to a "virtual shipyard," to aid the designers in addressing producibility from the start of design. During contract design, five competitively selected shipbuilders were brought onboard to help review the specifications, develop additional producibility improvements, comment on the implication of metrication and CALS, etc." [Tibbitts and Keane, 1995] Milestone 0 was in November 1990, and Milestone I was in January 1993.

The ongoing Strategic Sealift program also has significant potential for transition to a new 21st century acquisition strategy.[4] The program manager has characterized the program as "about as commercial as the Navy has ever gone." Fewer than 10 MilSpecs are being used. There were, however, more Contractor Data Requirements List (CDRL)

---

4 The Strategic Sealift Ships (T-AKR) are being built using a Circular of Requirements (COR) approach. The Navy issued a COR and RFP to industry, and shipbuilders then responded with a proposed contract design. Three yards were then put under contract to build the ships. The system is considered successful by NAVSEA personnel we interviewed, but even the program manager expressed reservations about using a COR for more complex ships, including the LPD 17. The response from some of the personnel interviewed was that the COR approach works if you are willing to accept what you get. This seems to preclude the Navy accepting on design response and contracting for a standardized ship. In other words, the COR should only apply up to the point at which a design is chosen. After that the contractor is guided by the contracted ship specification.

items. In some cases, the shipyards preferred the MilSpecs to commercial standards such as ISO-9000.

For the sealift program, yards were allowed to bid either conversions or new production, depending on which they believed they could better provide. The IPT concept was used. Current sealift ships have been operated by contractors since 1985 following a privatization study.

The timing and pace of ship procurement will play a major role in determining how efficiently ship construction proceeds. It may also play a role in determining which shipyards survive.

2. Acquisition Strategy Issues

There are several other issues pertinent to acquisition strategy. These are discussed in the following sections, grouped under the headings of design and construction.

a. Acquisition Strategy Issues Related to Ship Design

Extent of Navy Involvement in Contract Design and Detailed System Design. A key decision to be made by DoD is the extent to which NAVSEA should be involved in ship design. The early design stages are crucial to determining the cost, schedule, and performance of the delivered ship. While virtually no program-specific money is spent by Milestone I, the bulk of the cost and performance of the ship is "locked in" by this time. By Milestone II, roughly 80 percent of the cost and performance of the ship is locked in. Therefore, it is important to plan carefully in the early design process. [Huthwaite, 1994]

The Navy typically plays a greater role in ship design than do the other Services in designing other types of systems. Whether or not the Navy will be able to continue this level of involvement in view of the downsizing of government is an open question. Some efficiency is gained by keeping a single design staff within government rather than reimbursing for design staffs spread out among several shipbuilders. On the other hand, the limited design capability available at the shipyards may be hampering their competitiveness in the world market. In addition, the Navy as designer and ultimate operator has no incentive to reduce requirements. The LHA was a shipyard-designed ship, but the experience gained there does not shed much light on this issue. A variety of problems, many unrelated to design, prevent this program from being a fair test of shipyard design. The building yard encountered severe startup problems at a time of high

inflation in the U.S. economy. In addition, major design changes were necessary to propulsion control, cargo handling, and the ship's self defense capability. Cost growth was 50 percent even with a reduction from 9 ships to 5.

For the future, involvement of all major stakeholders through the IPT process is likely to raise the cost of early design. However, this approach has the potential to reduce total costs overall through a philosophy of getting things done right the first time.

Modular Design. Although some ship programs include modular elements, as a rule, ship designers have lagged behind aircraft developers in the use of modular construction. Use of modular components facilitates rapid incorporation of changes. Modularity also assists in cross-service interoperability and commonality, especially for C^3 systems. Modularity does cause a small penalty (estimated to be on the order of 2 percent) in weight and volume. Its use also require some changes in contract specifications for the shipbuilders and weapons builders. However, modular ships are easier to build, more interoperable, and easier to upgrade.

Prototyping. Given the small numbers of ships that are typically bought and the time and cost involved in designing and building the first ship, prototyping of complex ships is impractical and consequently is not used as frequently in shipbuilding as in other types of systems. As Tibbitts and Keane point out, "there is no real 'fly before buy.' In the case of the DDG 51 class, seven follow ships were under contract before the lead ship delivered, and three additional ones were under contract before the lead ship achieved initial operating capability (IOC) a year later, a multi-billion dollar commitment. The ship as a whole is not tested until after delivery to the fleet." [Tibbitts and Keane, 1995] Sub-systems are prototyped relatively frequently, of course, both to support concurrent development and to facilitate block upgrade. Other technologies such as simulation-based design and CAD/CAM should allow virtual prototyping and early verification of design features.

Suitability of Design to Modification and Upgrade. "The time to develop a major new system (e.g., Aegis, electric drive) is longer than the time required to develop the ship." [Tibbitts and Keane, 1995] The Navy has often handled this problem by initiating system development in advance of ship design and by using common systems whenever possible. To facilitate upgrades, it is necessary to continuously evaluate new technologies.

b. Acquisition Strategy Issues Related to Ship Construction

Extent of Navy Involvement in Combat System Procurement and Integration. Whether or not ship systems are furnished by the Government as GFE or by the contractor as CFE matters in ship affordability and affects acquisition incentives. Late arrival or defects in GFE can lead to large claims against the government. On the other hand, because the same combat system can be used on several classes of ship the government can usually acquire combat systems at lower cost than the shipbuilder can. Moreover, the government can shield the shipbuilder from significant risks in combat system performance.

In addition to combat systems, other items may be provided as GFE. In the contractor's view, this means that they have to rely on the government to provide a working system on time and ready for installation. In some instances this has been a source of turbulence in the shipbuilding process.

Change Orders. The volume of change orders can significantly affect a ship's cost. Change orders have many causes—true errors of judgment, poor choice in supplier, tardy recognition of an inconsistency, or use of new technology for example. Again, the government may be tempted to order more changes than are necessary or cost-effective to improve performance, and the builder may market change orders as a way of increasing revenue or "getting well" on a lowball bid. Strong central control and design discipline are required throughout the design and production process to avoid this.

Other Cost-Cutting Techniques. There are a number of ways to reduce the unit cost of the ships the Navy acquires. Among the measures, some of which will entail changes in ship performance, that can be taken are:

- Reduced combat system capability
- Reduced sustained speed, possibly by a reduction in the number of engines
- Alternative powerplants
- Alternative transmission systems or ship service power sources
- Dispersed auxiliaries and load centers to reduce piping, wiring, and ducting
- Alternative hull forms
- Reduced crew size
- Process improvement to cut rework
- Off-ship modular construction.

The extent to which the performance-impacting changes should be implemented would depend on a detailed assessment of the military capabilities required from the ship.

Dual Sourcing versus Early Down-Selection. Table 13 summarizes issues relating to dual source competition versus early down-selection. Dual sourcing has been extensively used by the Navy in both ships and missiles in an attempt to hold prices down and, in some cases, to improve quality. In the case of ship dual sourcing, the yards have bid aggressively on past programs, believing that their survival was at stake.

Dual sourcing typically requires an upfront commitment of resources to create capability to build the ship class at two yards. Often, technology transfer is required among yard personnel who do not trust one another.

The major potential benefit of competition is lower prices. This is important, particularly as the number of yards shrinks. If the remaining yards maintain enough capability to provide meaningful competition for each ship type, the yards cannot then wield monopoly power to raise prices without fear. As the defense industry shrinks, DoD is rapidly becoming aware of the danger of facing vertically-integrated monopolies in major product lines. The leverage created by competition creates incentives for the shipyards to design ships for effectiveness and efficiency and to pay attention to the government's needs for reliability and maintainability.

Another benefit of competition is the increased surge potential for current and future programs. Typically, when two yards build a ship class, both yards could increase quantity easily. Dual sourcing can also assist in maintaining a long-term industrial base.

Table 13. Competition versus Early Down-Selection

Factors Favoring Competition	Factors Favoring Early Down-Selection
Lower prices likely, especially if shipyards believe that their survival is at stake	Makes early industry involvement in IPT process easier
Prevents shipyard monopoly, which would lead to higher prices	Can still do subsystem competition
Increases surge potential, both for current and future programs	More consistent with likely future industry structure
Creates incentives for effective design	More orderly program management
Creates incentives for maintainability	Avoids upfront costs of establishing dual capability
	Incentive fee and award fee contracts may be effective (needs rigorous examination)

Nevertheless, the small quantity of ships planned over the next decade makes competition a costly strategy. Depending on how many yards consolidate or go out of business, it may not even be feasible. Therefore, some analysts are considering the advantages of early down-selection and considering other methods of injecting cost discipline.

Early down-selection makes the establishment of IPTs easier and more orderly. If there are multiple yards involved in the acquisition process, there can still be IPTs, but often there will be separate IPTs for each yard. With early down-selection, it is still possible to compete sub-systems, and the prime contractor can assist in this process. Moreover, the upfront and continuing costs of dual capability, including dual overhead structures, are avoided.

When the government is dealing with a sole source, however, the contract is critical. It is surprising how little rigorous analysis has been conducted of the effectiveness of different types of contracts. Carefully-drawn incentive fee and award fee contracts may have potential for encouraging a sole source contractor to meet the government's needs in a cost-effective manner. There has also been some theoretical work that suggests that the government can benefit by offering a contractor the choice of a low fixed-price contract (without use of the Truth in Negotiations Act procedures to discover costs) or a traditional contract with cost discovery. [Rogerson, 1992 and 1996] However, this theory has never been empirically tested.

Acquisition Reform Initiatives. Table 14 shows some potential acquisition reform actions, including their potential benefits and drawbacks:

Integrated product teams (IPTs) can be used throughout the acquisition process, in order to obtain the benefits of concurrent engineering. By involving manufacturers and maintainers early in the design process, it is hoped that the government will obtain cheaper ships, with more producible and more maintainable designs. The IPT process also involves a partnership between customer and contractor, rather than an adversarial relationship. A potential drawback of IPTs is that the teams can become so large that it is difficult to accomplish the work, and focus is lost.

Overarching IPTs were discussed previously as a means of OSD oversight of the Navy. They have similar advantages and disadvantages. In particular, there is some skepticism that OSD action officers will be given sufficient authority to commit their superiors to approving the work of the OIPT.

Table 14. Potential Ship-Related Acquisition Reform Actions

Action	Potential Benefits	Potential Drawbacks
IPTs	All benefits of concurrent engineering, including lower cost, more producible design, more maintainable design	Team becomes unwieldy, with everyone involved in everything
OIPTs	Problems surface early and are addressed Team vs. adversarial approach	Heavy consumption of time in meetings, subordinates not given sufficient authority to commit their superiors, diffuse accountability
Reduction of military specifications and standards, use of commercial specifications and standards	Reduced cost Increased use of commercial items More firms willing to do business with the government, increased competition	Can become meaningless In some cases, Military standards adopted if there is no commercial standard. Product may not meet military needs
Commercial-style competition	Lower prices, due to less time spent in writing detailed proposals and expanding the number of firms willing to do business with the government Government can appropriate best ideas	Political world may not accept high rewards for contractors Industry finds volatile profit margins, less able to plan
Cost as an independent variable (CAIV)	Lower costs based on cost-performance tradeoffs More maintainable systems Promotes multiple options and creative solutions	Lower-capability systems Requires ability to support cost-performance trade studies Difficult to enforce in sole source environment
Full and effective competition	Allows government to negotiate with best companies	May exclude some viable competitors

Military specifications are already supposed to be the exception rather than the rule. This can result in lower costs through increased use of commercial items. However, in shipbuilding, military specifications have been adopted by the commercial world, rather than the other way around.

Commercial-style competition has been presented as having the benefits of simpler acquisition and expanding the number of options available to the government. However, Congress may be unwilling to see firms earning the high profits typical of very successful firms. In addition, shipyards have been accustomed to stable profits due to government business and may not be happy about accepting the volatility that comes with the commercial style.

Cost as an independent variable (CAIV) is a major DoD initiative designed to establish acquisition and O&S costs as issues equal in importance with measures of system

performance and effectiveness. Ideally, CAIV would lower costs and result in more maintainable systems. However, CAIV implies that sometimes a lower-capability option would be chosen. It requires the ability to support and assess cost-performance trade studies. In the sole source environment that we may be moving toward, it is difficult to encourage multiple options and creative solutions.

Finally, while it has not yet been adopted, some government officials have argued that the requirements for competition should be relaxed to allow the government to negotiate with companies they deem the best. The drawback is the possibility of perceived unfairness and the possible exclusion of some viable competitors.

Incentives For Contractors and Contract Types. The strongest incentive for contractors may be the pressure of competition for this job and the desire for future work. Due to the decline in the number of shipbuilders, competition is becoming less of a motivating factor for the yards. Therefore, other incentives to keep costs under control need to be constructed.

In a cost-plus contract, there are perverse incentives to raise costs. DoD often tries to counteract this tendency through formal contractual incentives to cut costs. Relatively little work has been done in the area of how to construct effective incentives in major acquisition programs. Both incentive fees and award fees have been utilized in the past and should be considered for future awards as well. For the reasons noted earlier, the relationship between such fees and program success or failure are often difficult to measure in retrospect.

3. Health of the Industry

a. Number of Yards

Over the last 20 years there has been a significant decline in the number of yards. This has bearing on the ability of program offices to have effective competitions in development and production. Within particular product areas—e.g., surface combatants, carriers, support ships—the number of yards able to serve as prime contractor is considerably smaller.

b. Commercial Viability

The major shipyards face significant challenges in finding commercial work. A complex surface combatant is roughly 30 percent steel and 70 percent integration, while a

commercial tanker or bulk cargo carrier is roughly 70 percent steel and 30 percent integration. There are other major differences as well including: the degree of shock tolerance built into Navy ships which is considerably greater than for commercial ships, the need for damage control features in a Navy ship which enables it to keep fighting even when damaged in battle, and the necessity of carrying significant stores to sustain the crew and the combat system on long deployments. Commercial ships require none of these features.

c. Compatibility of Military Requirements and Commercial Work

There are several possible advantages for the Navy to mixing Navy and commercial work in the shipyards. These include:

- Sharing of overhead functions, such as administration and accounting
- Related to this, the possibility that the Navy can schedule construction for reasons of requirements or productive efficiency rather than for the need to maintain ready capability
- The benefits of cross utilization of innovative commercial design and production techniques
- Easier training of the workforce due to use of commonality and use of commercial standards where appropriate.

E. FINDINGS

1. Findings from Empirical Analysis

Ship acquisition programs have been considerably more successful than other programs for other system types in producing systems that meet cost and schedule goals. While some of the low cost and schedule growth observed in shipbuilding is due to differences in program structure (including late baselining), such differences do not apply to all of the successful ship programs.

The three findings with respect to acquisition initiatives are based upon both the quantitative analysis discussed earlier in the chapter and the program histories collected in Appendix A.

- Total package procurement is related to higher production cost growth and total program cost growth. Other system types exhibit the same results. The DD 963 and LHA programs almost bankrupted the shipyard. The AOE 6 had an arrangement similar to TPP—a fixed-price incentive contract for the lead

ship with an option for 3 follow ships. This was also unsuccessful—the AOE 6 had 30 percent cost growth.

- Design-to-cost appears to be a successful strategy. While it was not statistically significant, design-to-cost appears effective based on the program histories collected in Appendix A. The programs that had DTC were generally successful, despite some substantial differences in the technical difficulty and responsibility for the design. For example, the CG 47 was a modification of the existing DD 963 hull. While costs were higher than anticipated in development, this was made up in production. The DDG 51 is a Navy-developed design that employs the same propulsion plant as the DD 963 and CG 47 classes. The LHD 1 is another modification program that uses components from an earlier design—in this instance the hull and propulsion system of the LHA.
- Incentive contracts in FSD can lead to lower development cost growth. In particular, the CG 47 award fee strategy was successful.

The experience of the FFG 7 may also be instructive: the FFG 7 program strategy included design-to-cost together with extensive subsystem prototyping and modeling. Nevertheless the FFG 7 program had high cost growth. Three yards were involved with consequent problems in data exchange and change order control, all during a time of double-digit inflation.

2. Preferred Acquisition Strategy

Because of the disconnect between the rapid pace of technical change in combat systems and the long production cycle for ships, it is necessary to develop a technology strategy of continuous review. Figure 7 illustrates the current acquisition strategy and our recommended strategy. In the current process, the Navy is primarily responsible for all activities, including feasibility studies and preliminary/contract design, up to Milestone II. In the recommended process, the Navy performs feasibility studies, but at Milestone I the Navy establishes an IPPDT that includes all parties. Where possible, a circular of requirements is used, and contract design is performed by the bidders. The lead ship contract is a Cost Plus Fixed Fee (CPFF) let to a single yard. Follow ships are contracted for using FPIF or Fixed Price Award Fee (FPAF) contracts.

CURRENT STRATEGY

PHASE	CONCEPT DEVELOPMENT	PROGRAM DEFINITION/ RISK REDUCTION	EMD/PRODUCTION	IOC
MS	0 MS	I MS	II	
ACTIVITY	Feasibility Studies (Navy)	Preliminary/Contract Design (Navy)	Detail Design and Construction (Shipyard)	Shakedown

PREFERRED STRATEGY

PHASE	CONCEPT DEVELOPMENT	PROGRAM DEFINITION/ RISK REDUCTION	EMD/PRODUCTION	IOC
MS	0 MS	I MS	II	
ACTIVITY	Feasibility Studies (Navy)	Navy-led IPPDT Established/COR used where possible, contract designs prepared by bidders	Lead ship contract (CPFF) let to single team or yard. Follow ships awarded FPIF	Shakedown

Figure 7. Acquisition Strategies

Based on the assessment presented here the following actions should be discouraged:

- Undue contractor risk. Given the tenuous nature of the shipbuilding business, it does not make sense to do total package procurement for programs in which the design is complex and unproven. Forcing shipbuilders to "bet the company" to participate in a program can backfire against the government. The caution against undue risk also means that fixed-price development contracts should be discouraged. In development, the government should pay reasonable costs and should assist the contractor in making design tradeoffs.
- Complex requirements. Overstatement of requirements can prevent reasonable tradeoffs. While the long ship production cycle presents obstacles to the kind of evolutionary development possible with other types of weapon systems, tradeoffs still can be made.

Conversely, the following should be encouraged:

- Integrated product teams for design, production, and oversight.
- Early down-selection to a single yard. In the current industry environment, keeping two yards going may be too expensive for the government. If this is the case, down-selecting as early as possible makes sense.

- A simplified requirements process. Simplification of requirements, though use of a Circular of Requirements when possible, will help to encourage innovation. Wherever possible, commercial standards and practices should be used. Proven technology, both military and commercial grade, should be used as much as possible. The Affordability through Commonality initiative should be encouraged.
- Interoperability across services. The Navy should take care to ensure that its systems are interoperable with those of the other military services. Ships should be planned to take advantage of multi-Service standard systems, such as communications.
- Cost-plus contracts for lead ship design and construction. With close cooperation between the government and the shipbuilder, this contract type is likely to lead to the best outcomes.
- Risk sharing contracts for later ship construction. Once there is construction experience with a ship class and costs are well known, the yard and the government should share the risks. For later versions of a ship class, fixed-price-incentive-fee and fixed-price-award-fee contracts should be used. Incentives can be targeted toward cost reduction, maintainability, quality, or other concerns based on fleet experience.

REFERENCES

1. Freund, John E., *Mathematical Statistics*, Prentice-Hall, Englewood Cliffs, N.J., 1971.
2. Hackworth, David, "Shipyard Contract is Waste at its Worst," Harrisburg, PA Patriot News, August 11, 1995, p.11.
3. Huthwaite, Bart, *Strategic Design: A Guide to Managing Concurrent Engineering*, Institute for Competitive Design, 1994.
4. Kmenta, Jan, *Elements of Econometrics*, New York, Macmillan, 1986.
5. Nelson, J.R. and Karen W. Tyson, *A Perspective on the Defense Weapons Acquisition Process*, IDA Paper P-2048, September 1987.
6. Perry, William, *Acquisition Reform: A Mandate for Change*, Memorandum, February 1994.
7. Perry, William, *Reengineering the Acquisition Oversight and Review Process*, Memorandum, April 28, 1995.
8. Rains, Dean A., *Naval Ship Affordability Studies*, Briefing, March 1994.
9. Rogerson, William P., *An Economic Framework for Analyzing DoD Profit Policy*, R-3860-PA&E, Rand Corporation, 1992.
10. Rogerson, William P., *The Incentive Effects of Using Audited Cost Projections to Determine Prices for Fixed Price Contracts*, Unpublished Manuscript, Northwestern University, 1996.
11. Tibbitts, B.F. and R.G. Keane, Jr., *The Warship Design Process: Making Design Everybody's Job*, Briefing, 1995.
12. Tyson, Karen W, J. R. Nelson, Neang I. Om, and Daniel M. Utech, *The Effect of Management Initiatives on the Costs and Schedules of Defense Acquisition Programs*, Paper P-2722, Institute for Defense Analyses, November 1992.

This page intentionally left blank

II. SHIP DESIGN

Ship design and production are presented in two separate chapters as a matter of convention; however, the two are closely related and cannot and should not be separated completely. A great deal has been learned about shipbuilding over the past 15 years, through such programs as the Navy's MANTECH and the National Shipbuilding Research Program as well as through industry and Navy studies. One of the consistent findings is that the practice of designing a ship in isolation from the producers and operators does not work. This chapter addresses ship design, but in the context of the total system, which includes the life cycle from concept development through production to final disposition.

The first section summarizes the recent history of Navy design process and strategy, the Navy design organization and the relationships between design and production. The next section addresses product-oriented design and construction innovations in the 1990s. Concurrent engineering and the Navy's Generic Build Strategy are discussed next. The historical development and apparent effect of design and engineering technology, including CAD/CAM/CIM and simulation-based design, are then presented. The next section compares and contrasts U.S. Navy design organization and strategy with those of foreign navies and commercial practice. A brief findings section concludes the chapter.

A. NAVY SHIP DESIGN PROCESS AND DESIGN STRATEGY

1. Overview

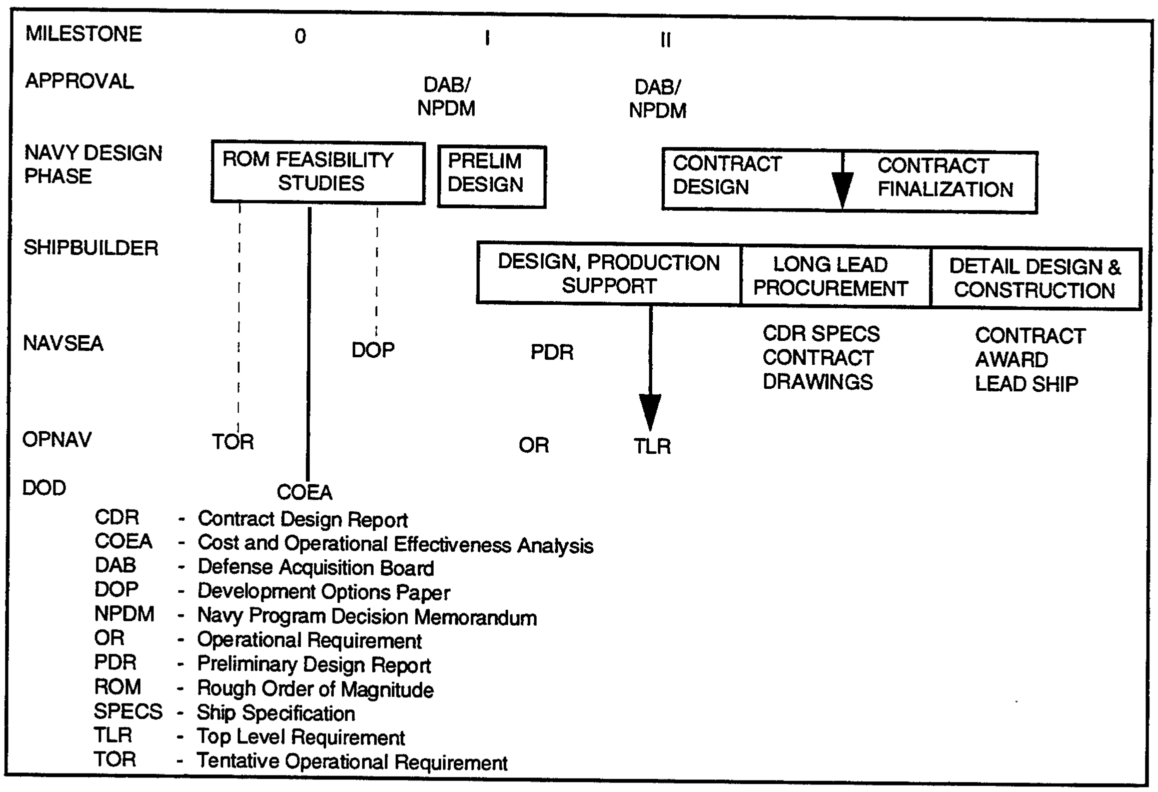
Navy ship design phases consist of preliminary, contract and detail design. Feasibility and Concept studies precede and, to some extent, overlap preliminary design. The Navy, in general, retains responsibility for the design process through the contract design phase. As a rule, the shipyards are responsible for detail design.

- Feasibility Studies consist of discussions and analyses of threat, missions, and technological and budgetary risks. Feasibility studies are often preceded by Rough Order of Magnitude (ROM) studies. Elapsed time for the studies and

reviews that lead to Milestone I, including the Cost and Operational Effectiveness Analysis (COEA), averages approximately 16 months.

- Concept design concentrates on tradeoffs to establish technological risk, capabilities, weapons system, ship size, crew size, main propulsion and the number of ships to be built.
- Preliminary design determines the basic hull shape and weight, and sea keeping characteristics of the ship. Approximate locations of decks and bulkheads are determined and block size and weight are defined.
- Contract design produces a design in sufficient detail that a shipyard can knowledgeably bid for detail design and construction.
- Detail design results in work instruction drawings and specifications from which the ship is built. Detail design begins with transition design, during which the design team transitions from a system-oriented perspective to a zone-oriented view of the ship.

Figure 8 summarizes current design practice in terms of milestones.



Source: [Ryan and Johns, 1991]

Figure 8. Typical Recent Navy Ship Design and Production Sequence

2. Navy Design Practice - 1950 to 1990

This section summarizes the Navy's historical design practice in terms of the degree of control and extent of participation by the shipyards.

a. Design in the 1950s

The Navy has experimented with several approaches to ship design since the end of World War II. In the 1940s, 1950s and early 1960s the Navy had separate preliminary and contract design branches as well as design organizations at the Navy shipyards. These organizations designed the ship and produced a complete bid package, including contract plans and specifications. Shipbuilders or design agents were frequently brought in to help, but the Navy's in-house design organization was in charge. [Tibbitts, Keane, Covitch and Comstock, 1993] Both lead and follow ships were constructed in Navy and private shipyards. Construction contracts were not competed; ships of a class were allocated to Navy and private shipyards. Contracts were typically spread to several yards. For example, LPD 7 through 15 were built by two yards under four contracts. The ships were delivered an average of 27 months late and at an average of 125 percent of the original contract price, not counting change orders. This system produced some very successful programs from the Navy operator's point of view, including the first SSNs, SSBNs, CVNs and CGNs. However, U.S. Navy ships were more expensive than similar ships built in foreign yards, the shipbuilding base was declining from the peak wartime years, shipyards were making little profits, and unique systems proliferated, resulting in increased costs of repair and training. [Carpenter, Finne, 1972] The relationship between the Navy and shipbuilders was non-adversarial and shipbuilding claims were infrequent. [Tibbitts, Keane, Covitch and Comstock, 1993] Of course, this characterizes the situation today in those cases where there is little competition among shipbuilders (e.g., for aircraft carriers and submarines) and cost plus contracts tend to be used.

b. Design in the 1960s: Total Package Procurement

The Navy discontinued new construction in government shipyards after the initial flight of the LST 1179 class, and Total Package Procurement (TPP) was introduced by Secretary of Defense McNamara. TPP was a radical departure for Navy shipbuilding; responsibility for design was shifted from the Navy to industry. The Navy conducted studies during the Concept Formulation phase to determine the basic performance characteristics and performed necessary Research and Development (R&D). A Request

for Proposal (RFP) was issued for complete design analysis based on the requirements document (Circular of Requirements). Two or more contractors were then awarded fixed price contracts to develop a complete ship proposal. These proposals included contract plans and specifications, detailed construction plans and an analysis of Total Life Cycle Costs. Each proposal was evaluated and the most cost-effective plan was selected, based on technical design, planning and cost. After incorporation of strong points of the other proposals, a fixed price multi-ship/ multi-year contract was awarded. Two ship classes were built under TPP, the Tarawa class of amphibious ships (LHA 1-5) and the Spruance class destroyers (DD 963-992). Both programs were awarded to Litton Industries for construction in the Ingalls shipyard located at Pascagoula, Mississippi.

It is generally conceded that TPP was not a success from the perspective of cost over-runs and delay. It is less clear that TPP was unsuccessful in terms of the final product or in a few key elements of the acquisition process that survive today. The DD 963 was designed with future modernization or conversion in mind. The DD 963 was a general purpose destroyer, but the ship was designed using a modularity concept with space left to accommodate future modernization or conversion to an AAW (DDG) version. [Collins, 1975] The hull was used for the DD 993 and CG 47 classes, both considered to be highly successful combatant ships. The DD 963 power plant—the General Electric LM-2500 marine gas turbine—has been used in every Navy surface combatant built since the Spruance as well as in the AOE 6 class fast combat support ships.

A perhaps more important observation is that TPP was never really given a fair appraisal. From the very beginning, problems arose in the new yard in which the ships were to be built. Litton's Ingalls Shipbuilding Division West Bank shipyard complex, where the LHAs and DD 963s were built, was designed to use high technology modular techniques, and an in-line flow pattern in order to gain the advantages of assembly line series production. Five of eight commercial ships intended to "de-bug" the new yard were moved to the east bank yard to make way for the LHAs. The LHA program, which was reduced from nine to five ships, experienced delays of up to six years. The LHA delay resulted in increasing the amount of concurrent work for the two programs, thereby delaying the DD 963 program. The conscious decision of the yard to give preference to the DD 963 program resulted in even more serious delays in the LHAs.

The planned sequence of the two programs was such that three parallel bays were to be dedicated to the DD 963 program. However, as front-end delays brought the two programs into closer contact than originally planned, DD and LHA modules were intermingled in the bays and the first two DDs were built conventionally in the erection area. The third bay was not made available to the DD 963 program until the laying of DD keel number seven. Additionally, a basic premise of TPP design procedure was apparently violated by the Navy for both programs. The shipyard was to have had total responsibility for ship design and performance as well as material control within the limits spelled out by the contract. Both parties agree that in the beginning the Navy maintained a completely "hands-off" policy to comply with the total package concept and to avoid opening the door to claims that they interfered with the contractor. At the same time, the contractor wanted guidance regarding military characteristics beyond his experience level. Neither party was able to resolve the problem contractually and communications broke down between the two. As a result, the Navy eventually became heavily involved in the design process, with major modifications required to correct perceived deficiencies in propulsion control, cargo handling and C^3I all without waiting for the proof of concept trials which would follow delivery of the first ship. In the end years, the attitude was to finish the ship and sort out the contractual issues later. Both parties assumed a proportionate share of the overrun, the Navy got its ships, and the shipbuilder got a brand new competitive shipyard.

c. Navy Ship Design in the 1970s: Top-Level Requirements

The perceived failures of Total Package Procurement, along with the desire for better attention to cost/performance tradeoffs, led to Top Level Requirements and Top Level Specifications, such as Design to Cost (DTC) in the late 1970s. All major systems were required to establish a DTC goal and to work toward that goal. The Navy also took more responsibility for design, with the return of a central design organization in the Navy. The first ship design of this period was the FFG 7 class of missile frigates. NAVSEA conducted feasibility and preliminary design in-house, but two shipbuilders were competitively selected to provide support during contract design. At the completion of contract design, one of the yards, Bath Iron Works (BIW), was authorized to start detail design and procurement of long lead time propulsion items. Bath Iron Works built the lead ship, and the remaining ships were awarded in flights of two or four to BIW, Todd Seattle and Todd San Pedro. This design strategy also was applied to the MCM 1 class of

mine countermeasures ships. Both the FFG 7 and MCM programs were apparent successes from the viewpoint of the Navy design organization, but the design strategy was not used again after the MCM 1 class. [Tibbitts, Keane, Covitch and Comstock, 1993] and [Tibbitts and Keane, 1994]

d. Navy Ship Design in the 1980s

In the 1980s, the Reagan buildup provided sufficient funds for increased numbers of ships—the Navy's stated goal being a 600-ship fleet. However, with the increased funds and several highly visible scandals came increased Congressional concern about fraud, waste, and abuse and an increased desire for competition. Each military service was required to establish a competition advocate, and dual sourcing was prevalent. Whether or not dual sourcing was successful for shipbuilding depends on one's point of view. It may have been beneficial from an industrial base standpoint, and may have kept some yards in business that would not have survived otherwise. However, there is a built-in conflict between the lead and follow yards because of changes to detail plans and conflicts in production practices among the yards. Additionally, none of the yards benefit from increased throughput and series production to the extent that would otherwise be possible. For a time during the 1980s, development contracts for ships were fixed-price. It is generally conceded that the strategy of fixed-price development was not successful.

There was no single standard design strategy in the 1980s and many variations were tried. The 1980s was a period during which U.S. shipbuilders were becoming aware of advances in shipbuilding productivity in other countries, particularly Japan. Nearly all shipyards instituted some degree of zone construction, generally starting with Hull Block Construction. Concurrently, there was a greater awareness of the impact of design on producibility. This was reflected by greater Navy design organization awareness of the benefits of early participation by the shipyards in the design process. Concurrently, the Deputy Assistant Secretary of the Navy (RDA) Ship Programs brought pressure for NAVSEA to include shipyard participation in all phases of design.

Ship designs originated in the 1980s included the MCM 1, DDG 51 Aegis (Flight I), Seawolf (SSN 21), T-AGOS 19, LHD 1, LSD 49, and the MHC 51. For the DDG 51 the original plan called for feasibility studies, concept design and preliminary design to be done in-house, and a contract let to a single shipbuilder for contract design. At the urging of COMNAVSEA the plan was changed to allow the Navy to do the DDG 51 contract

design in-house because of affordability and risk. Three shipbuilders were contracted to assist the Navy design team. The yards became familiar with the design and many yard suggestions were incorporated by the Navy, but the yards could not agree on the zone boundaries or on a common build strategy.

The Navy again opted for an in-house Navy design for the T-AGOS 19 class based on risk considerations. Although there had been a prototype, the design was extremely innovative and complex. Shipyard involvement was required and representatives from 10 yards were invited to participate (without compensation) in preliminary and contract design. A large number of producibility enhancements suggested by the shipyards were included in the design, but the winning shipbuilder was not one of the design team participants.

The LHD 1 and LSD 49 Cargo Variant classes were follow on programs to previously built ships. Feasibility studies were accomplished in-house and preliminary and contract design contracts were awarded to the yards that built the "parent" ships (Ingalls and Avondale, respectively). Producibility features were included in the designs, which were accomplished at the shipbuilders sites. NAVSEA involvement was somewhat limited by the distance of the design teams from Washington; NAVSEA control, however, was not relinquished.

For CVN 76 the shipyard--Newport News Shipbuilding (NNS)--was involved throughout all design phases. This program is atypical because there exists only a single private shipyard with the capability to construct aircraft carriers. However, in terms of similarity to previous CVNs, the program is not too different from the LHD 1 or LSD 49 classes. In all three cases the shipbuilder was identified early. It is generally agreed that incorporation of producibility features and integration of weapons systems into the ship is facilitated by the early identification of the shipbuilder.

The use of a Circular of Requirements (COR) for many auxiliaries was an important change in philosophy during the 1980s. Under this concept, contractors designed the ship in response to the Navy's statement of requirements.

c. Navy Ship Design in the 1990s

Ship design in the 1990s has been influenced primarily by declining budgets, technology advances and the Navy's desire to introduce world class manufacturing practices to control costs. With the end of the Cold War, it has become increasingly clear

that in order to preserve a Naval ship industrial base, we must work smarter. The Navy can probably no longer afford the inefficiencies inherent in dual sourcing, tight centralized control and execution of design within NAVSEA, micro management of the production process, and complex restrictive military specifications that it applied in past decades.

Thus far, the 1990s have been characterized by a very small number of naval ship designs. The most notable of these is the LPD 17 amphibious transport dock assault ship. From the beginning of feasibility studies, the LPD 17 has been treated as a model for naval ship design in the 1990s. The ship is the first Navy ship to be metric, commercial standards are being used to the extent possible, and producibility is a key objective of the design team. One of the first actions was the appointment of a simulated ship production department under the leadership of a Producibility Task Manager. This "surrogate shipyard," was called the Product-oriented Design and Construction (PODAC) working group. The group was tasked with introducing design-for-production concepts early in the design phase through interaction with the LPD 17 designers. [Wilkins, Singh, Cary, 1995] It is too early to know the outcome, but it is clear that the Navy is attempting to introduce many innovations into the design and management of the production of the ship.

B. CURRENT NAVY SHIP DESIGN INNOVATIONS

Although elements within the Navy had been developing innovative design initiatives throughout the last decade, in 1990 the NAVSEA Chief Engineer set the stage for formalizing and further developing these initiatives within the framework of the Naval establishment. The Chief Engineer, SEA 05, with the support of the Office of the Assistant Secretary of the Navy (ASN(RD&A)) and the Commander NAVSEA ".... initiated an effort to improve the performance of the Naval ship design, acquisition and construction (DAC) process." [Horne, 1991] The objective of the project, as stated by the Chief Engineer, was:

> "To identify the crucial actions necessary to improve the quality of future ship designs (i.e. meeting customers requirements), to reduce ship construction costs and life cycle costs, and to reduce the time required from establishment of requirements to delivery of the lead ship." [Horne, 1991]

DAC was instituted as part of the overall Navy's adoption of Total Quality Management (TQM). TQM was adopted by the Department of the Navy in 1989 to:

- Improve mission capabilities in defense systems
- Increase customer satisfaction
- Achieve continuous improvement in all Department of the Navy processes
- Open lines of communication, reduce rework, and improve quality and productivity.

The DAC program was implemented in two phases. Phase I began with a kick-off meeting of shipbuilders, equipment suppliers, design agents and representatives from throughout the Department of the Navy. The purpose of the meeting was to:

> (a) provide overall direction for improvement efforts, (b) get advice on "where to look first" based on the expertise of the Navy and industry representatives, and (c) develop momentum and support for the subsequent efforts. [Horne, 1991]

Seven overlapping phases of the ship acquisition process were defined and Process Action Teams (PATs) were constituted to represent and analyze these phases. Since many issues cross over the boundaries of a given team, an eighth team (Process Definition and Integration) was added. This team was made up of the team leaders of the other seven PATs. This process and the eight phases are shown in Figure 9.

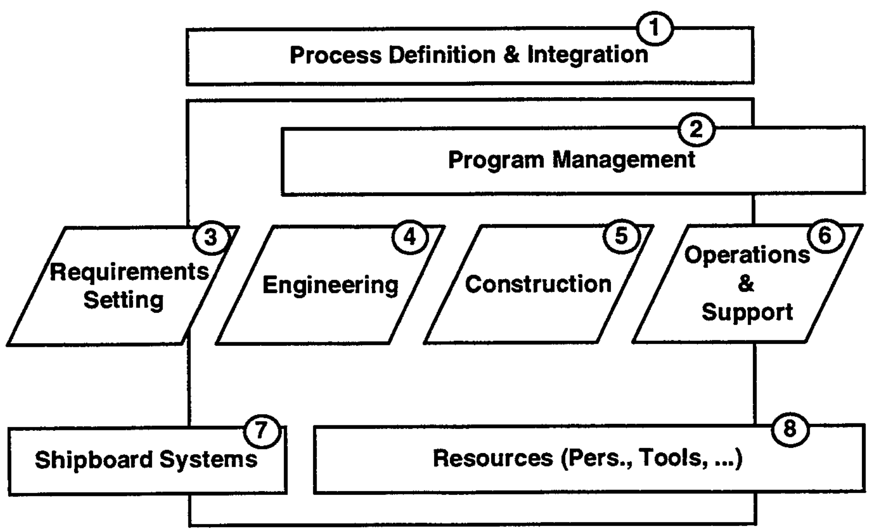


Figure 9. The DAC Process and Team Organization

Source: [Ryan and Johns, 1991].

DAC Phase I defined a detailed model of the design, acquisition and construction process. Additionally, this model was analyzed, process roadblocks were identified and proposed solutions were developed. In Phase II of DAC, a second workshop was held on 6-7 May 1991, the results of Phase I were reported and the concept was more fully developed. Trends in ship design and total costs and development times were reported, and an attempt was made to define quality in the DAC process. [Ryan and Johns, 1991] The interdependence of the seven elements of the DAC model was explored in more detail, and a list of strategic DAC improvement principles, was proposed. These are listed in Table 15.

Table 15. DAC Process Strategic Principles

Customer Focus/ Customer Understanding
Long Range Planning
Project-oriented Design Teams
Concurrent Design of Ship Product and Construction Process
"Best Known Method" Build Strategy
Flexible Change Management
Life Cycle Cost (LCC) Decision Making
Continuity of the Ship Development Process
Life-Cycle 3-D Product Model
Availability of Appropriate Resources
Institutionalized Feedback System
Fact-based Management
Process Technology Management

Source: [Tibbitts et al, 1993].

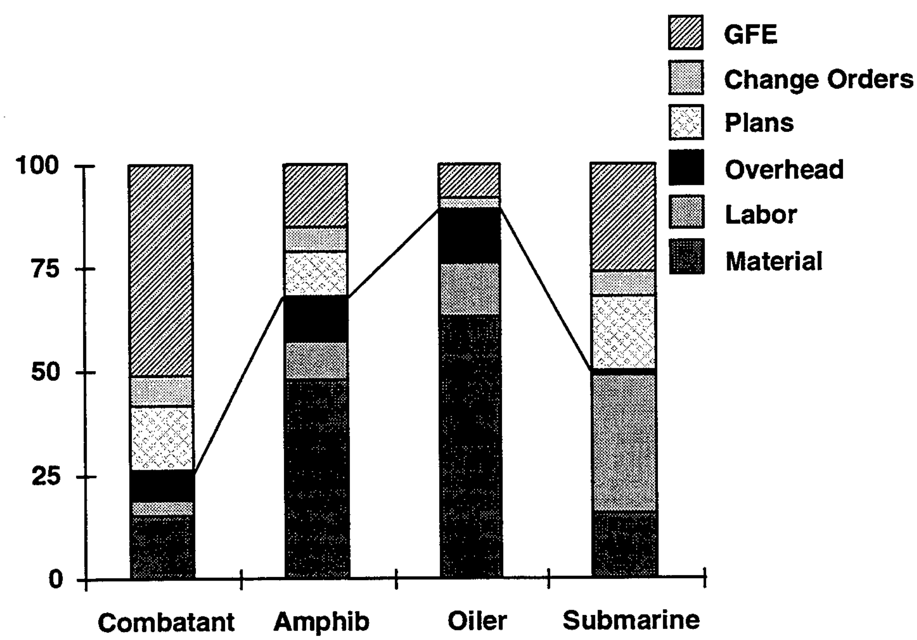
The analysis reported at the DAC Phase II workshop, along with the principles listed in the table above, provide guidance for the still on-going Phase II DAC project. The remainder of this chapter will build on the historical material previously presented and the material presented at the DAC II workshop.

1. Importance of Design

One of the purposes of the Phase I DAC workshop was to get advice on "where to look first." As stated previously, it is impossible to separate ship design and ship production completely because they are highly interdependent. However, we started with design because of its impact on all of the remaining phases of the DAC process, including

operations and maintenance. Design represents only 2 percent of the Life Cycle Cost (LCC) for a typical Naval ship. However, it is estimated that more than 80 percent of total costs are determined before the completion of contract design. It is therefore vitally important that the process gets off to the right start during the design phase.

Figure 10 shows ship acquisition cost for four types of Navy ships. An important finding evident in the figure (and presented at the DAC II workshop) is that weapon systems represent approximately 50 percent of the acquisition cost of a typical combatant. This points up the importance of the integration function and the control of material that is generally handled as Government Furnished Equipment (GFE). Put another way, the costs under the control of the shipbuilder—material, labor, and overhead—are only 25 percent for a combatant ship--80 percent for an oiler. For the four types of ships, labor is generally the factor most controllable by the shipyard, but one which represents only about 15 percent of yard controlled cost. Note also that shipyard production labor represents less than the typical cost of change orders for a combatant ship.

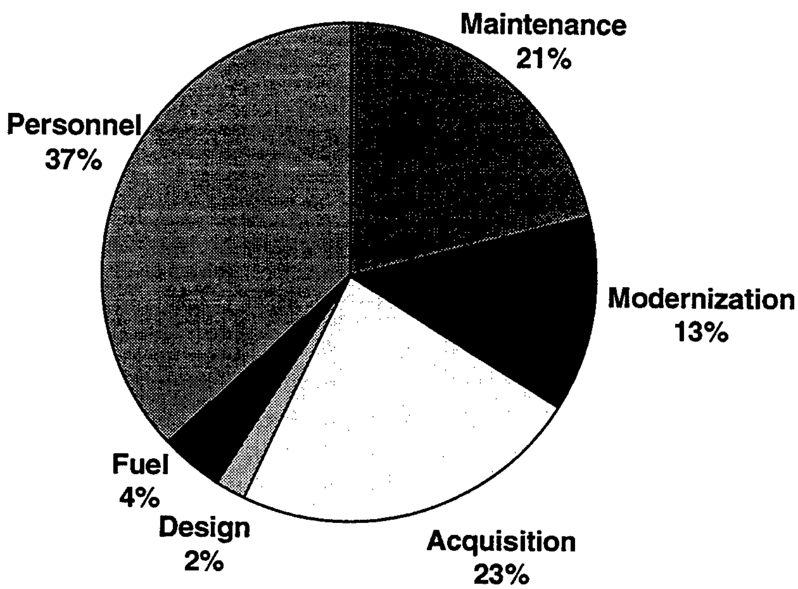


Source: [Ryan and Johns, 1991].

Figure 10. Ship Acquisition Cost (End Cost) Breakdown

Figure 11 shows typical LCC costs broken down by design, fuel, personnel, maintenance, modernization, and acquisition. Note that personnel costs are the greatest

contributor to LCC cost (37 percent compared to 23 percent for acquisition). Numbers of personnel are driven by requirements for damage control, watch standers—particularly Condition I—and maintenance. It is not clear that damage control or watch standing requirements can be reduced. Foreign navies have reduced crew requirements by moving some maintenance ashore and contracting out. The British were able to reduce crew size on the Type 23 Destroyer by 40 percent in this way. In the U.S. Navy, an attempt was made to reduce crew size on the FFG 7 by moving some maintenance ashore. However, a systems approach was not taken, and the required infrastructure was not provided. [Tibbitts, Keane, Covitch and Comstock, 1993]



Source: [Ryan and Johns, 1991].

Figure 11. Ship Life Cycle Cost Breakdown

2. Product-Oriented Design and Construction (PODAC)

Product-Oriented Design and Construction (PODAC) is essentially the Navy's statement of Group Technology Ship Production. Since 1980 the U.S. shipbuilding industry has been slowly moving toward recognition of world standards for the manufacture of complex systems. The existing group technology model for shipbuilding was developed initially by Henry Kaiser during WWII and exported to Japan in the 1950s by Elmer L. Hann, formerly the General Superintendent of Kaiser's Swan Island yard.

The Japanese further developed the concept through the application of statistical control methods to the shipbuilding process.[1] [Chirillo and Chirillo, 1985] During the 1980s every major U.S. shipyard attempted to transfer this technology to their yard through the employment of Japanese consultants and participation in the National Shipbuilding Research Program (NSRP). It is not clear that all of the yards were successful in implementing the technology, but during the decade of the 1980s both the industry and Navy personnel became aware of its promise. It has been conjectured that any lack of success in adopting Japanese methods was because U.S. yards adopted isolated parts of the technology in a piece-meal manner, rather than understanding and adopting the total system. Group technology shipbuilding requires a total commitment to a company business and build strategy which treats the product and the process as a total system. The direct technology agreements of the 1980s usually were aimed at a particular process such as material handling, planning, steel processing, accuracy control, or outfitting. As stated by Lamb, Allan, Clark and Snaith (1995), "The U.S. shipyards into which the new specific item approaches were being introduced did not fully understand the underlying principles and the manufacturing systems in which the approach originated."

Group technology, also called family manufacture, is defined as:

> "The logical arrangement and sequence of all facets of company operation in order to bring the benefits of mass production to high variety, mixed quantity production." [Ranson, 1972]

Two essential elements of this definition are the phrases "all facets" and "high variety, mixed quantity production." Ship design and construction should embody the concept of a total system, and a product built to order, not for inventory. Ships consist of interim products. These interim products are value added inventory, which, until the ship is delivered, represent costs rather than assets. Many of the concepts relevant to ship design and production were presented in a 1991 industry-led study sponsored by the Navy's Mantech office. The study termed such a system the agile manufacturing system. This study sums up, for our purposes, a most important concept regarding design.

---

1 As early as 1947 the Union of Japanese Scientists and Engineers recognized that statistical control methods could significantly improve quality and producibility. In the summer of 1950, Dr. Edward Deming of New York University gave 35 lectures to Japanese top managers and engineers. By the spring of 1981, Deming had made 19 trips to Japan and accuracy control had become firmly entrenched as a part of group technology shipbuilding. [Chirillo and Chirillo, 1985]

> "Design is not the province of engineering, not even of engineering and manufacturing jointly. Instead, representatives of every stage in a product's life cycle, from materials employed in its manufacture to its ultimate disposal, participate in setting its design specifications. Information thus flows seamlessly between agile manufacturers and their suppliers, too, as well as between manufacturers and their customers, who play an active role in product design and development under agile manufacturing." [Nagel and Dove, 1991]

Since the 1970s the Navy has attempted to get the shipbuilders involved earlier in the design cycle. This began as an effort to enlist the expertise of the shipbuilders, but during the last decade or so it has become clear that there are many more important reasons for getting the shipyards involved earlier. The shipyard that builds the ship needs to incorporate features which reflect its unique production process (producibility features). More important, perhaps, is that the ship design must be responsive to many customers, including the material suppliers, and those who are responsible for operations and maintenance throughout the life of the ship. Throughout the remainder of this chapter we will describe and discuss design technology and its relation to designing the ship as a total system. These include concurrent engineering, CAD/CAM, Simulation Based Design and networking complex systems.

C. CONCURRENT ENGINEERING

The concept of Concurrent Engineering originated in industry to consider all aspects of the life cycle in the early stages of the process. U.S. manufacturers, particularly in the auto and film industries, faced competition from Japanese manufacturers in terms of the time and money it takes to design a new product and bring it to market. Rather than "throwing the design over the wall" and expecting manufacturers to be able to produce it easily, concurrent engineering advocated the involvement of manufacturers in the design process. The concept has been greatly expanded since its inception, to include not only manufacturing, but the eventual user of the product, suppliers, and all aspects of the company developing and marketing the product. Clausing [1994] goes beyond what he calls basic concurrent engineering in his description of Total Quality Development. In his book, he introduces the term world class concurrent engineering and attempts to develop a rigorous framework for the concept. We will use the term concurrent engineering to mean what Clausing calls world class concurrent engineering throughout the remainder of this study.

The Navy has, during the past two decades, attempted to involve the shipbuilders in the early design phases. However, concurrent engineering goes much further than just the shipbuilder. The DAC improvement program reports indicate that other customers must also be brought into the design process. The operators, support personnel, combat and support systems developers, and suppliers also have a stake in the design. In order to realize the benefits of a true systems engineering approach all of these stakeholders should be represented on the design team. Figure 9, shown previously, essentially defines the organization for concurrent engineering. The DAC improvement program was the beginning of the Navy's move to implement concurrent engineering in the ship design process. This was followed up, in 1993, by the establishment of a Product-Oriented Design and Construction Working Group for the preliminary design of the LPD 17.

1. Integrated Product and Process Development Teams

The Integrated Product and Process Development Team (IPPDT), also called the Integrated Product Team (IPT), is the implementing system for the concept of concurrent engineering. An IPPDT is a multi-disciplinary team that is involved in the design and production process from the very beginning.

Several types of IPPDTs can be implemented in ship acquisition. They can be formed for ship design, contracting, or program management. Oversight of NAVSEA programs is now being conducted by an Overarching IPT (OIPT) rather than by the conventional milestone reviews. In all cases, the defining factor is the presence of the widest possible set of stakeholders—in many cases involving both government and industry, and including personnel expert in all phases of the life cycle of the ship.

Design IPPDTs with shipbuilder participation have great potential. Among the benefits are early adoption of a generic build strategy that can facilitate group technology ship production. The CVN 76 design was a start toward using the concurrent engineering concept. The design team included participation from NAVSEA, NAVAIR, Newport News, Naval Warfare Centers, and design agents.

For the LPD 17 program, a notional build strategy was developed during preliminary design. The design team was collocated at the time of feasibility studies rather than preliminary or contract design. This was driven by the need to develop and assess over a dozen alternative ship concepts. The LPD 17 was also the first ship to be designed under the revised 5000 series of regulations, which place greater emphasis on Cost and

Operational Effectiveness Analysis. The building process was simulated in a "virtual shipyard" to allow the designers to address producibility from the very beginning. Among the key benefits were aligned decks and bulkheads for modular construction, a highly producible hull form, a reduced number of types and sizes of material, and increased standardization and commonality.

2. Navy Design and the Generic Build Strategy

The Generic Build Strategy was introduced by the Navy as an outgrowth of the effort to introduce producibility features early in the preliminary design phase. Recognizing that changes in the design process were needed in order to keep up with changes in ship production, the Navy assigned a Producibility Task Manager (PTM) as part of the LPD 17, then called the LX, preliminary design team. The PTM was responsible for reviewing all elements of the design in order to identify areas where design changes could reduce costs without conflict with operational requirements, maintainability or reliability.

A primary task of the PTM was to insure that the ship design would be compatible with the production facility and methodology of the yard where it would be built. In order to do this, a Generic Build Strategy (GBS) was developed. The LX was the first Navy program to use a GBS. One of the first actions was the appointment of a simulated ship production department under the leadership of the Producibility Task Manager. This "surrogate shipyard," was called the Product-oriented Design and Construction working Group. The group was tasked with introducing ship design for production concepts early in the design phase through interaction with the LPD 17 designers. The PODAC Working Group consisted of contractors and independent consultants who were "knowledgeable of the amphibious ship production process and who possessed an understanding of modern (advanced) ship construction practices." [Advanced Marine Enterprises, 1994]

An important aspect of the project was not to impose a build strategy on the eventual shipbuilder. Rather, the stated goal was to produce a design which could be built efficiently by any of the potential bidders without significant redesign, or modification of yard facilities or production methods. To assure this, five shipyards were invited to interact with the design team, and to comment on elements of the design as it developed, including items which they believed to be detrimental to their ability to compete for the contract.

The output of the PODAC Working Group consisted of:

- Producibility improvements intended to achieve a more production friendly design
- The hull block plan
- Generic sample schedules
- Facilities and equipment requirements
- Construction controls.

These are discussed briefly in the paragraphs that follow.

a. Producibility Improvements and Design for Production

Producibility recommendations fall into the following general categories:

- Hull form
- General arrangements
- Machinery and machinery arrangements
- Structures specifications.

Producibility features do not appear to be particularly revolutionary. There is little mention of the use of CAD to eliminate interferences, although it is assumed that this will be part of the contract design work. An effort is underway to determine the impact of integrating Affordability Through Commonality (ATC) concepts within the LPD 17 Contract Design Package. Producibility features include parallel midbody, straight frames, modular sanitary and machinery spaces, and standardized major openings and space arrangements, subsystem package units (zonal electric and HVAC), standardization of stiffener location and sizes, one sided welding and sleeve couplings for joining modules, and the use of weld through primer. These are only a few examples. The elimination of HY-80, or other steels which require heat treatment, for crack arrestors is being investigated as is the need for crack arrestors entirely. [Wilkins, Singh, and Cary, 1995]

b. Hull Block Plan

The hull block plan appears to be the most extensive effort undertaken by the PODAC working Group. Zones were defined and numbered according to significant differences in major functions, complexity of construction, material ordering requirements

or shipyard accounting classifications. Block sizes and breaks were then determined according to the following criteria:

- Block size
  - Length and width of plates available from manufacturers
  - Transverse bulkhead spacing
  - Maximum weight and size of outfitted blocks which can be handled and transported within the prospective yards
  - Location of major longitudinal bulkheads and other major structures
  - Amount of on-block outfitting to be accomplished before erection
  - An effective method of erection of the blocks
- Normal block break criteria were established, to be altered only when some characteristic of the structure or arrangement could be shown to override the producibility aspects of the construction sequence.
  - All block breaks to be above the deck and aft of a transverse bulkhead
  - Stiffeners on transverse bulkheads to be located on the forward side
  - Blocks to extend from one transverse bulkhead to the next
  - Block widths not to exceed 10 meters
  - Block heights to be one deck high. except along the sides and bow, where space arrangements allow higher blocks.

c. Schedules

All LPD 17 schedules are based on a 66 month contract period (18 months for pre-construction and 48 months for construction). Except for the major milestones, which are normally part of the contract, schedules are the shipbuilders responsibility. Major milestones for the LPD 17 are Start Construction, Lay Keel, Stern Release, Launch, Inclining, Dock Trials, Builders Trials, Acceptance Trials and Delivery.

Schedules included in the Generic Build Strategy are:

- Key Event Schedule. The key event schedule provided by the PODAC group is intended to be an example and contains generic events considered typical but not inclusive.

- Master Construction Schedule. The master construction schedule is a top level schedule which provides both the sequence and duration of events. From this schedule the shipbuilder develops the hull block erection schedule. The hull erection schedule drives major events such as fabrication, outfitting, and material procurement. The generic hull block erection schedule was used by the PODAC group to determine a Long Lead Time (LLT) material schedule. Manufacturing lead times for similar ships were used to determine Required In-Yard and Required Purchase Order times.
- Master Material Ordering Schedule. Material Control is one of the most important functions in Group Technology shipbuilding. Material controls the entire production process. Make-or-buy decisions, and Just-in time delivery begin with the design process and must be followed through by the material control people in order to insure that workers have the requisite parts when needed.

d. Facilities and Equipment Requirements

The stated intent of the GBS was to not preclude any shipyard capable of building the LPD 17. "While the more modern shipyards are product-oriented and have facilities based on the principles of group technology, traditional construction facilities are not excluded from this build strategy." [Advanced Marine Enterprises, 1994] Although this statement seems to be in conflict with the overall purpose of the project, it is perhaps an indicator of actions that may have to be taken if the naval ship industrial base is to be saved. This same philosophy is embodied in the government's regulations concerning competition among sub-contractors. Time is a valuable resource, and the total cost of waiting for competitive bids may be greater than sole source procurement from a reliable and responsive contractor. Similarly, the GBS should encourage, and be built around efficient, product-oriented shipyards.

Regardless of the above statement, the GBS is purported to have been developed to reflect best practices in outfitting prior to hull block erection. Block sizes are optimized for zone outfitting and to facilitate erection in order to maintain balanced work flow using process lanes and platens away from the erection area. The stated intent of the build strategy is to maximize On-unit and On-block outfitting. The build strategy also is intended to facilitate pre-outfitted equipment modules. These modules, developed by the

Affordability Through Commonality project include standard outfit packages for reverse osmosis water purification plants, fire pumps, steering gear, sanitary spaces, and machinery spaces. Scheduling the procurement and installation of ATC modules was carried out as part of the GBS project and is reported in [Christensen and Koenig, 1995].

e. Construction Controls

Both the Navy and shipyard impose certain controls in order to insure that the design and construction process delivers a quality product. This is an area where, in the past, the difference between performance specifications and micro management have become somewhat blurred. For instance, Navy contracts generally specify that the shipyard will have a quality control system acceptable to and certified by the Navy. The Navy role is then to insure that the yard is complying with their own system. However, in interviews with yard and Supervisor of Shipbuilding, Conversion and Repair (SUPSHIP) personnel, it appears that SUPSHIP inspectors frequently go well beyond checking compliance with the system and engage in hands-on quality assurance inspections.

For the LPD 17 GBS, the PODAC working group specified the more obvious controls, including:

- Ship fairness and alignment procedures
- Corrosion control and preservation
- Weight control, noise control, weld integrity, quality assurance, data control
- Ship protection and security
- Accuracy control.

As stated in the LX (now the LPD 17) GBS study, a thorough knowledge of these controls can help the ship designer to develop designs which minimize the potential disruption that these controls might cause to the ship production process. A question which should perhaps be asked in specifying a GBS, is whether the GBS is over-specifying procedures which should be determined by the yard. Accuracy control for instance, is at the heart of group technology shipbuilding. It is also one of the least well understood processes in U.S. yards. In observing U.S. yards it is clear that very little progress has been made in the last 15 years in the implementation of this most important discipline. Yet, every yard seems to believe that they have a fully adequate accuracy control system.

Perhaps the Navy is justified in taking the lead, even at the risk of over specifying controls in this area.

f. Generic Build Strategy: Overall Assessment

The Generic Build Strategy appears to be a significant improvement over past Navy design practice. Inclusion of shipyard participation in the studies and preliminary through contract design phases evolved over a period of three decades with many false starts and reversals. However, it seems that we should ask the question: is a GBS merely a substitute for early selection of a contractor team, who would be responsible for developing a build strategy which is compatible, in all respects, with their business strategy, shipbuilding policy and build strategy, and yard facilities? Is a GBS actually a second best solution, in the economic sense, to extend NAVSEA control over the design process and defer down selection and thereby facilitate competition among the shipyards?

Retention by NAVSEA of full design responsibility through contract design was a characteristic of Navy design in the 1980s. The reason invariably given was that it was too risky to turn more responsibility over to the shipyard. This poses the question of how best to manage risk and who is better prepared to bear the risk? We should also ask which is the greater potential cost; the cost of not getting exactly what we perceive as meeting the operational requirement, or the cost of inhibiting efficient production by the contractor. Part of the answer to these questions hinges on whether the Navy can devise a system of controls which assures that the product meets requirements without interfering with detail design and construction.

An obvious benefit of the GBS is that it gets the design process off to the right start and serves as a medium for educating the shipyards on what is desired. The Navy is certainly the best judge of what it wants. The Navy is, therefore, in the best position to conduct feasibility studies, and, with participation of all qualified potential yards, preliminary design. The Navy is also in the best position to avoid one of the major pitfalls of the concurrent engineering process. Clausing [1994] points out that the independent Process Development Team concept, though clearly successful in the short-run, may suffer from three long-run problems. These are (1) functional obsolescence, (2) weak organizational learning, and (3) stale technology. The PODAC team members must have a functional home or they may lose the expertise that makes them so valuable as team members. By assembling an ad hoc team for each ship program, the pitfall of team

members becoming project-oriented, to the detriment of the expertise which makes them valuable contributors to the team, may be avoided.

A second strength is that concurrent engineering and the GBS provide a forum for learning by the yards as well as the Navy. The advantages of Product-Oriented Ship Production and disciplines such as Accuracy Control have been known to the U.S. shipbuilding industry for at least 15 years. But, their practice has been ineffective at best. U.S. shipbuilders have failed to understand why Japanese yards, with higher labor rates, can produce ships at less than half the cost of the same product in a U.S. yard. The IPPD teams provide an interchange of information among customer and producer. The GBS also provides the Navy with leverage to encourage efficient and productive controls, including an approved Accuracy Control system. Of course, along with that leverage goes the responsibility to insure that the contractor has an adequate system and then to refrain from micro-managing or tampering with that system.

It is frequently conjectured that the qualified bidders for Navy work have sufficiently similar construction technologies and processes so that a GBS would be acceptable. Although this may be true today, it is not necessarily the case that it will be true indefinitely, particularly as yards adopt world class methods and technology.

It can be further argued that the Navy's retention of responsibility for design through the contract design phase is somehow efficient in that the yards do not have to keep duplicative design organizations. It may, in fact, be less costly to have one design organization rather than paying the cost of design groups spread out over several shipyards. However, if the shipyards are to re-enter the world shipbuilding market, they will have to be capable of accomplishing preliminary and contract design.

Perhaps the most obvious negative aspect of the GBS, as presented, is that it may go on too long. Preliminary design is systems oriented, at least in the beginning. Contract design should include transition design where the design team must transition to a zone orientation. At this point the design must be more responsive to the shipbuilder's production facilities and processes, and to teaming arrangements with suppliers. Long lead time material and integration of the weapons system also become important issues.

The PODAC group did not include among its membership representatives from shipyard design or production engineering organizations or suppliers. Suppliers were contacted for advice as needed, and the shipyards were invited to comment on the

findings. Whether this is adequate representation in order to fully benefit from the concurrent engineering process remains an open issue.

Strong points of the GBS appear to be in producibility and the hull block planning during preliminary design. This is somewhat of a dichotomy in that these are closely related to the builder's facilities and way of doing business. But, this is the time in the design process when the Navy can exert the most leverage in obtaining the desired product, when the Navy can exert the most influence over standardization and later efficiencies. For instance, this is the time when the Navy can lay the ground work for introducing incentives and guidance for accuracy control and utilization of ATC. Perhaps the issue is not how but when. If 80 percent of costs are determined prior to and during preliminary design, then Navy management should be willing to maintain maximum control through preliminary design and then relinquish some control over the remainder of the design phase in order to free the contractor from counter productive interferences with their yard and production strategy. The GBS as used for LPD 17 appears to be an effective means of introducing concurrent engineering into preliminary design. It does not appear to be entirely appropriate for contract design, when each yard should be concentrating on a build strategy unique to its production facilities and methods.

D. COMPARISON OF THE U.S. NAVY DESIGN PROCESS WITH FOREIGN NAVAL AND COMMERCIAL PRACTICE

1. Foreign Naval Ship Design

The ship acquisition process of Canada and most European navies is very similar to that of the United States in terms of the design phases described earlier. The UK, Italy, Germany and Canada all have design phases similar to those of the United States and all retain Navy control through contract design. Detail design and construction contracts are competitively let to private shipyards, although some Italian ships are built in public yards. The entire acquisition process is controlled within the Navy in France, and detail design and construction are accomplished in public shipyards. The UK system is very similar to that of the United States in terms of design phases, design control, and competition. The main difference seems to be in the way R&D is handled. Whereas the U.S. Navy initiates R&D concurrent with preliminary design, the British begin R&D as part of a combined concept studies and design phase. [Andrews, 1992] This follows UK weapons

development philosophy generally, in that concept development and R&D are often begun prior to a well established requirement. Canada puts more emphasis on design-to-cost and an upper limit on cost is determined during the feasibility study phase.

Japanese naval ship design is patterned after commercial practice, and is characterized by the use of performance specifications and concurrent engineering. The Japanese use a phased system similar to that used in the United States, but fewer personnel and a smaller number of organizations are involved. Design labor-hours for the Aegis DDG (JDS Kongo) were 1.2 million compared to 6.0 million for the DDG 51 and 3.0 million for the CG 47. [Martin, McGough, Rains, 1990] Some savings were undoubtedly realized for the Kongo because the Japanese studied the DDG 51 in detail before and during the Kongo design. The CG 47 design hours provide a better comparison with the Kongo in that the CG 47 hull was a variant of the DD 963 hull and the same main machinery was used in both classes.

Contracts are not competed, and the shipyard starts detail design earlier than is the rule in the United States. [Summers, 1993] Because the shipyard is selected prior to contract award, and is a key player in the early design phases, contract design is much less detailed than in the United States. It appears that preliminary and detail design include much of what is accomplished during contract design in the United States. Contract design is accomplished by the government, and takes only about six months to complete. For the Kongo, concurrent design included the shipyard design team, production and suppliers, and these stake holders were fully involved during preliminary design. Detail design was started 21 months before contract signing.

A major difference between U.S. and foreign approaches to design seems to be in contract design. This is an area where U.S. practice itself has varied considerably over time and across programs. Contract design, who does it and whether the details of the resulting contract drawings are legally binding on the construction yard, has a profound effect on producibility, the shipbuilder's build strategy, and ultimately the cost of the ship. During contract design, detailed specifications are developed by various NAVSEA technical codes, and the design and costs are finalized. In the past the technical codes have not always coordinated their work, resulting in conflicts which must be resolved during detail design and construction. [Ball, 1992] Under the U.S. system, specifications are frozen during contract design, and later change requires formal submission of an Engineering Change Proposal (ECP). The LPD 17 design process, using concurrent

engineering and the GBS, is addressing many of the flaws in past design practice. It remains to be seen whether the GBS will produce the same results as the strategy used for the Japanese Kongo.

Contract design was contracted to the building shipyards for the FFG 7 and the MCM 1 classes, and preliminary and contract design were done by the shipyards for the LHD 5, LSD 49 CV, and MHC 51. Because there is only one yard capable of building CVNs, the builder (NNS) was involved throughout all design phases of CVN 76. For the LPD 17 the Navy will be responsible for contract design.

2. Commercial Ship Design Practice

Commercial operators can either contract with a shipyard to build the owner's design, or buy a shipyard-standard design—usually with minor modifications to individualize the ship to suit owner requirements. Paulus [1995], through interviews with six ship owners and operators, found that all of them used the latter system. This method is generally used by commercial customers because it allows the shipbuilder to use series production and offers lower prices. Additionally, the NAVSEA owner survey determined that:

- All owners use a similar acquisition process.
- All use performance specifications. The amount of detail varies with the ship type.
- All use fixed price contracts.
- There are no change orders.

The process generally begins with the owner issuing a Requirements Document of 3-10 pages, followed by a request for inquiries and an RFP. These and the shipyard responses require 30-90 days. This phase is followed by approximately 5-11 weeks of proposal review and clarification, at which time the owner selects one shipyard and issues a non-binding letter of intent. The selected yard then prepares the contract specification (about 400 pages and appears to be equivalent to preliminary design with many elements of a contract design package in the Navy process). The contract package includes general arrangements, midship section, machinery arrangements, habitability arrangements, cargo or piping, trim and stability calculations, speed and power calculations, and a makers list. This is followed by about 4 weeks of detailed negotiations during which the parties agree

on contract specifications, the makers list, contract clauses, price, penalties and payment schedule.

Contracts are generally fixed price with penalties and a one-year warranty. The payment schedule usually consist of payments of 20 percent commencing at contract signing and at major milestones through delivery. For approximately 6 months after contract signing, the yard is engaged in preparing construction plans, material lists are prepared, material is ordered, and final approvals obtained. Start Fabrication is at the end of this period and the ship is delivered one year later.

The Navy is currently planning to use a modified form of the above system for the ADCX, a point-to-point underway replenishment ship. PMS 325 is putting together a team consisting of Navy and industry members similar to a PODAC working group. The personnel responsible for procurement of auxiliaries have previous experience with the performance specification/IPT approach. The Strategic Sealift Ships (T-AKR) are being built using a Circular of Requirements (COR). The Navy issued a COR and RFP to industry and shipbuilders then responded with a proposed contract design. Three yards were then put under contract to build the ships. The system is considered successful by the NAVSEA personnel we interviewed, but several Program Managers expressed reservations about using a COR for more complex ships, including the LPD 17. The response from some of the personnel interviewed was that the COR approach works if you are willing to accept what you get. This seems to beg the issue. The Navy is not precluded from accepting one design response and contracting for a standardized ship. In other words, the COR should only apply up to the point at which a design is chosen. After that the contractor is guided by the contracted ship specification.

E. SHIP DESIGN AND ENGINEERING TECHNOLOGY

1. CAD/CAM

Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) are the common descriptors for automation tools used in the design and manufacture of complex systems. CAD has typically included such things as geometric modeling (illustrated in Figure 12), engineering analyses, kinematics studies and work instructions. Typical CAM applications include robotics-control procedures, process planning, and shipyard-management-system coordination. However, as the emphasis has changed from

simply product development to Integrated Product and Process Development (IPPD), the term Computer-Integrated Manufacturing (CIM) is more encompassing and more relevant.

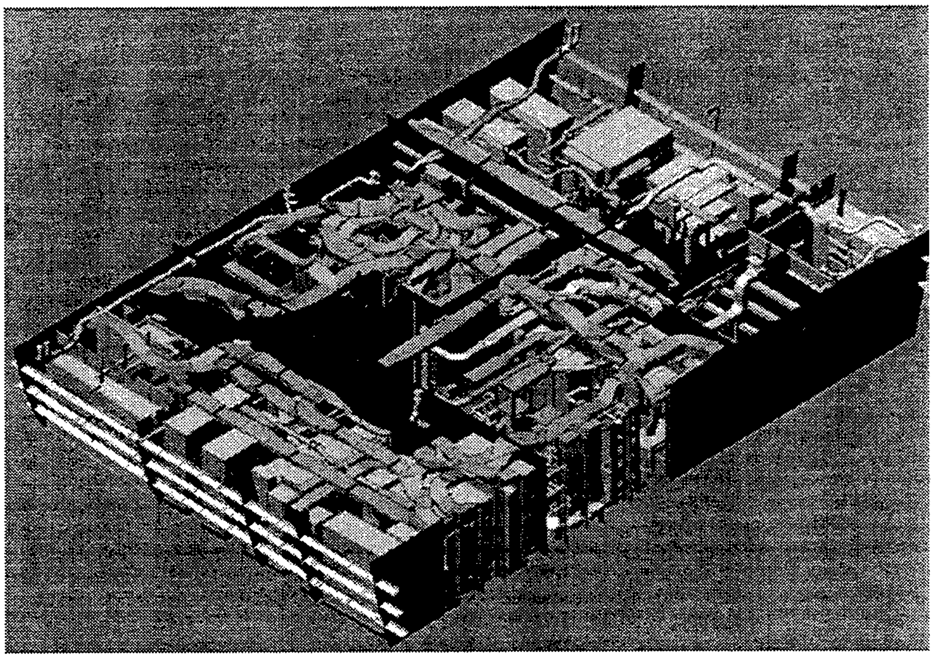


Figure 12. Illustration of CAD Geometric Modeling

A highly developed CIM system might encompass elements in all phases of the cradle-to-grave life evolution of the project. Such a CIM system would include feasibility-study and preliminary-design scoping tools for the concept development stage of the project. As the project matures, computer-aided engineering (CAE) tools will aid in estimating such things as stresses in the product and acoustic, magnetic, and electromagnetic signatures. Kinematics studies can be conducted using an additional set of tools. As the project moves into the later design phases, cost- and schedule-estimating tools become more important as do purchasing and material-control tools. In the final stages of design, computer-aided drafting tools are very important and tools to produce numerically controlled (N/C) machine instructions and instructions for robotic-cutters and -welders are exercised. Throughout the construction process, accuracy control, quality assurance, planning and scheduling, material control, inventory control and accounting tools are continually used. After delivery of the product, parts catalogs and configuration-management tools take on an increasing role. These tools and their role in the design-and-

manufacture process are illustrated in Figure 13. Many of these tools are currently well developed and readily available.

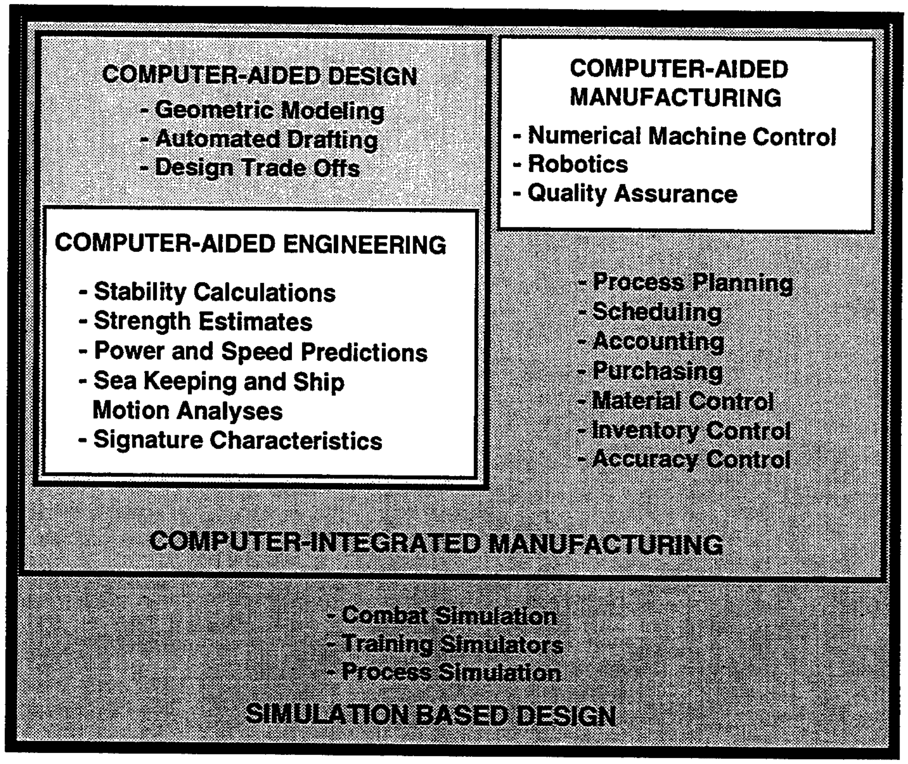


Figure 13. Role of Computer-Aided Tools in Design and Manufacturing

The benefits of a well-developed CIM system are numerous. CIM tools allow feasibility studies and concept designs to be performed much more quickly. Although this does not result in large direct-cost savings, these tools enable the designer to consider many more design options in a fixed amount of time and thus increase the likelihood that effective and efficient designs will be found. Changes to established designs can also be investigated quickly with these tools. As the tools and the associated data bases mature, the designer will be able to draw upon proven designs and be able to use reliable, proven design data. Other benefits include being able to easily reassess, modify, and reuse build strategies, to establish and employ standards, to transfer data digitally amongst suppliers, builders and buyers, and to interface with computer graphics.

Although the individual pieces of CIM exist in most of the large shipyards today, the integration of these tools into a design-and-manufacture system is not yet complete. Perhaps the most pressing automation problem facing the shipyards today is the lack of a

unified database to support all of the functions described above for the IPPD of a Navy ship. For the most part, this automation problem is not technological; rather it is dominated by a need to define the elements in the unified database, the product process model, and by a need to have a standard to support the electronic exchange of data between systems.

CAD/CAM systems are much further along than CIM systems in providing an integrated environment. Currently, there are seven major integrated CAD/CAM ship design systems in operation throughout the world. Brief descriptions of these systems are given in Table 16. Most of these systems provide for direct N/C links for lofting and cutting plates and stiffeners. Some also support N/C bending of plates, stiffeners, and pipes, automated pin-jig setting, and robotics programming. Most of these systems also require a three-dimensional product model for the highest levels of integration.

Table 16. CAD/CAM/CIM Systems Used in Shipbuilding

PROGRAM	COUNTRY	DEVELOPER	NOTES
AutoSHIP	Canada	Coastdesign	Used by small to medium-sized shipyards
FORAN	Spain	Senemar	Licensed by over 100 shipyards in 19 countries
HICADEC	Japan, Denmark	Hitachi Zosen and Odense Steel Shipyard	
HULLTECH	Great Britain	BMT Group	Follow-on to BRITSHIPS
NAVSEA CAD-2	United States	Intergraph	Supports design, construction, maintenance, overhaul and repair
NAPA	Finland	Wartsila Corp.	
TRIBON	Sweden and Germany	Kockums Computer System	Combination of AUTOKON, STEERBEAR, and SCHIFFKO. This most commonly system by large shipyards

While CAD/CAM systems are fairly mature, the management system piece of CIM is in its infancy in U.S. shipyards. Results of a study performed by the Marine Board Committee on National Needs in Maritime Technology of the National Research Council [Steward and Hashell, 1995] indicated that:

> "U.S. shipbuilders lack the information management systems that are needed to compete in world markets."

In particular, current management systems lack the ability to gather and analyze customer data, to develop bids quickly and flexibly, and to accurately track and evaluate

costs. These features are critical to competitiveness in world-wide commercial ship construction, but have not been needed to respond to the yards' primary customer, the U.S. Navy.

Another aspect that the NRC study found lacking in current CIMs is process simulation. In fact, the study recommends that process simulation should receive the highest priority of all technological areas considered, because "it gives structure to all the other efforts to improve the competitiveness of U.S. shipbuilders." This recommendation builds on the concept of IPPD; designers should concurrently be designing a product and a process. The process defines the outline for the overall development program. For example, if the ship is built in blocks, it should be designed in blocks and these blocks should flow smoothly through the ship-construction process. The NRC believes that the United States has a natural advantage in this arena with its strong computer-simulation capabilities.

a. Assessment of Computer Aids in Shipyards

A study by the National Shipbuilding Research Program [NSRP, 1993] identified computer programs that are currently in use in major shipyards and the reasons that the shipyards selected these programs. Additionally, the study identified how effectively the shipyards were using the programs and the degree to which these computer tools were integrated into the overall production process. The conclusions from this study indicate that the foremost obstacle to increasing implementation of computer aids in the shipyards is not technological; industry has proven quite adept at developing and demonstrating new methods and technologies. Instead, the prime deterrent to implementation is an institutional inertia that prevents these systems from being incorporated into the process. This inertia is not confined to the shipyards, but as the study found:

> "Participants at the May 1992 conference were startled to find that the collective consensus clearly shows that no progress with better computer aids is possible without a very significant breakthrough in the extent to which yards, suppliers, designers, and customers cooperate."

The study used a "Feasibility Matrix" to determine the degree to which 11 different automation objectives were currently implemented in the shipyards. This rating ranged from an objective's being conceivable or theoretically possible to its being routinely used

in the production process. The 11 objectives are listed in priority order below, additional details are provided in Table 17:

1. Process Definition - Use automation tools to describe, measure, and improve the overall design and production process.
2. Simulation-Based Design - Integrate the tools used throughout the design and production process and simulate the ship as a product that is widely accessible to everyone involved.
3. Product Model Exchange - Ensure that information can flow freely between the suppliers and the shipyards and the customer.
4. Product Process Model - Ensure that the appropriate information is captured in the PPM. Product Model Exchange works to ensure that the data can be physically transferred, PPM works to ensure that the data is functionally complete.
5. CALS Implementation - Provide digital product models that customers can access on-line.
6. Human Resources Innovation - Guarantee that every employee in the process understands the computer aids, concurrent engineering, and team building.
7. Industry Cooperation - Establish joint efforts to provide common databases, common software, and mechanisms for sharing information.
8. Expert Systems - Develop systems that can capture the experience of ship designers, shipyard managers, and ship construction processes.
9. Configuration Management - Track the design and construction process changes throughout a project's life.
10. Generic Modular Ship - Use the ideas of Affordability through Commonality to assemble a national library of reusable design modules.
11. Service Life Support - Ensure that the Simulation-Based Design objective includes automated crew training aids, computer aids for operations at sea, and product modernization.

Three of the top four priorities—Process Definition, Product Model Exchange, and Product Process Model—were mature enough that the participants in the survey ranked them as "Early Adopters"—that is, these concepts had already been tried on a small scale. However, none of the top priorities had passed into common practice even though no technical challenges prevented this.

Table 17. Recommended Approach for Achieving Automation Objectives

1. Process Definition	2. Simulation-Based Design	3. Product Model Exchange	4. Product Process Model
• Benchmark competitors • Document current processes • Make sure computer aid is essential to process • Automate efficient and necessary processes • Develop metrics to measure progress • Create costing structures that accurately reflect expended effort • Analyze process improvements • Develop process simulation tools • Prioritize automation evolution • Reestablish process engineering as a discipline • Invest first on systems that improve competitive advantage • Improve baselining technologies • Have management and operations groups jointly define products and processes	• Implement seamless integration from design through implementation • Develop an all inclusive Product Process Model • Use intuitive and simple user interfaces • Implement concurrent engineering • Integrate business operations with ship data models • Make computer tools accessible to yard personnel • Implement distributed databases • Integrate proposal estimates, detail definitions, work accomplishment and contract reporting	• Initiate data exchange project for the shipbuilding supplier industry • Use standards and not the current winning technology to define the architecture • Develop interchange standards • Fund prototype applications that use the NIDDESC information model • Implement PDES	• Develop a shipbuilding data dictionary • Develop an information technology plan featuring data and function integration • Document information required to manage • Create a specification for information independence • Identify shared conceptual schema for ship data modeling

Table 17. Continued

<table>
<tr>
<td>5. CALS Implementation
• Replace drawings with product models
• Provide on-line access to product data
• Require CDRL's to be written to pass product model information
• Encourage vendors to supply product data with products
• Provide contract awards only to reliable suppliers
• Establish relationships that support the entire life cycle
• Create efficient systems to gather cost data
• Involve the customer in review of configuration and reporting requirements as cost driver
• Establish customer capability to produce product models required by CDRL
• Make CALS a way of life
• Substitute process reliability for granularity of data collection</td>
<td>6. Human Resource Innovation
• Empower employees in the shipyard
• Expose management and workers to best processes for process improvement
• Ensure management understanding of computer aids
• Implement concurrent engineering
• Overcome organizational and cultural barriers to change
• Identify and document best practices in team building and team empowerment
• Provide university work study programs in the maritime industry</td>
<td>7. Industry Cooperation
• Establish a consortium for shipbuilding software development
• Provide knowledge transfer across industry
• Form customer, innovator, producer councils to project the future
• Create leadership forums for the industry
• Establish a Shipbuilding America Network
• Implement shipbuilding shareware
• Create centers of excellence for shipbuilding
• Form joint technology assessment teams
• Establish electronic communication within the industry</td>
<td>8. Expert Systems
• Create expert systems for ship design
• Implement parametric design concepts in shipbuilding
• Capture design decisions as part of the model
• Integrate expert systems with CAD, planning, and manufacturing systems
• Develop expert systems for shipyard management</td>
</tr>
<tr>
<td>9. Configuration Management
• Apply configuration management to shipyard processes
• Understand the discipline and training of configuration control
• Design a system that documents the as-built product</td>
<td>10. Generic Modular Ship
• Maintain a national library of reusable design modules
• Create a consortium of navy shipbuilders to create a joint commercial endeavor
• Develop modular designs
• Investigate building commercial and military ships in the same facility
• Generalize navy designs to generic shipbuilding designs</td>
<td>11. Service Life Support
• Develop a ship repair strategy that uses advanced technology
• Extrapolate new construction methods to lifetime support
• Develop automated crew training aids
• Use shipboard computer applications during a shipbuilding program
• Add value to ships by incorporating computer aids for operation</td>
<td></td>
</tr>
</table>

In Product Model Exchange and Product Process Model, the U.S. shipbuilding industry is the world leader. The U.S. shipbuilding industry ranked behind "Best in the World" practice in nearly all other objectives. In CALS Implementation and Service Life Support, the U.S. shipbuilding industry was on a par with best practice. For each of the eleven objectives, specific recommendations were made for the way ahead.

b. Product-Data-Exchange Standardization Efforts

To realize the full potential of reusing designs of ship modules, having on-line digital product catalogs, CALS, and SBD, an efficient means for transferring data between unlike systems must be developed. Two approaches can be taken to enable this data transfer, (1) the development of product data exchange standards—every system can "speak the same language" and (2) the development of interfaces that translate data from one system into the format required by another. For the most part, U.S. shipyards today must rely on the latter method; they must develop software to translate the digital data. This is an improvement over having to rekey in data from hard copy, but is much less efficient and more prone to error than having a common data exchange language. Additionally, these direct translators must be reprogrammed every time a CAD/CAM system is upgraded or replaced. This section describes efforts to standardize an exchange language.

One of the earliest efforts at standardization was started in 1979 with the U.S. Air Force's Integrated Computer-Aided Manufacturing (ICAM) Project. This project brought together two large manufacturers, General Electric and Boeing, and the National Institute of Standards (NIST) (then known as the National Bureau of Standards) to develop a neutral data exchange file format. This work resulted in the Initial Graphics Exchange Specification (IGES). IGES Version 1.0 was first published in January 1980 and became an American National Standard in 1981. An industry effort continued work on IGES and, as the need to pass more than simply graphics information emerged, a new effort began to develop a Product Data Exchange Specification (PDES).

The IGES/PDES Organization (IPO) continues to enhance both standards. In 1988, PDES was proposed as an international standard for data exchange. In the international arena, this project is known as Standard Electronic Protocols (STEP). The IPO is continuing to develop STEP and it is the intent of the United States to adopt STEP so that there is one global standard for manufacturing technology.

An ongoing Navy-led effort for data exchange standards is the Navy-Industry Digital Data Exchange Standards Committee (NIDDESC). This work, begun in 1986, is a cost sharing effort by NAVSEA and the marine industry to develop transfer mechanisms for product models. The NIDDESC is based on the PDES work and has developed six application protocols:

- NIDDESC Ship Piping Application Protocol, Version 0.6
- NIDDESC Ship HVAC Application Protocol, Version 0.3
- NIDDESC Ship Electrical/Cableway Application Protocol, Version 0.2
- NIDDESC Ship Outfit and Furnishings Application Protocol, Version 0.1
- NIDDESC Ship Structure Application Protocol, Version 0.4
- NIDDESC Ship Library Parts Application Protocol, Version 0.4

The NIDDESC standards provide a useful "common ground" for shipyard-to-shipyard and shipyard-to-NAVSEA data transfer. As was discussed before, an interim approach to electronically transferring data is to develop translators. If this approach is taken so that each of the major shipyards could transfer data to each other as well as to NAVSEA, 42 separate translators would be required. However, if the participants can all transmit data to and receive it from a common system (i.e., NIDDESC) then only 14 translators would be needed. Additionally, if one of the participants were to change systems, only 2 translators would need to be modified for the NIDDESC approach vice the 12 translators that would have to be modified without NIDDESC. As reported in a recent paper, the major shipbuilders in the U.S. are well on the way to having the capability to communicate via NIDDESC protocols [Billingsley et al, 1992].

c. Application of Advanced CAD/CAM

LPD 17. The Navy's LPD 17 Program Office is making innovative use of advanced design tools.[2] In particular, 3-D geometry models have been developed for use during the contract design phase and a suite of detailed kinematic and dynamic computer models have been built to analyze and optimize the ship's boat handling system. In the future, NAVSEA hopes to go beyond 3-D geometry models and begin using 3-D product models so that both design and production problems can be uncovered and resolved

2 Information for this section was provided by [Tibbitts, 1996].

during contract design rather than remaining hidden until detail design, or even worse, until the ship construction process itself.

The steps taken by the LPD 17 program to develop a full 3-D geometry model represent a major advance. Utilizing CAD 2 engineering workstations, the fluid systems design team (comprised of the NAVSEA systems engineers, experienced CAD operators, representatives from selected NAVSEA field activities, and design agents) developed a set of fully integrated piping design models. The models include related equipment such as compressors, strainers, dehydrators, and pumps and are being used to model the ship's distributive systems, and to develop 3-D models of machinery compartment arrangements.

The 3-D models are also being used to check for interferences in several highly congested areas in the ship. Specifically, the models have been used to check the piping system, ship arrangements, ship structures, and other distributive systems (such as ventilation ducting and electric power cables). Several potential interference problems were identified when the two latest configurations of the models were superimposed on each other. In previous contract designs, this type of detailed interference analysis proved very difficult. Many design problems would not be discovered until after award of the shipbuilding contract (and at times not until well into construction), resulting in costly and time consuming rework. The models allow necessary changes to be identified early in the development cycle when the cost to effect them is low and the designer has maximum flexibility.

The 3-D design tools are also being used to improve the in-house engineering design process, and could eventually be used by the shipbuilder to improve the transition from design to production. Through use of this capability, the following specific design improvements have been achieved:

- 3-D digital models of designs of selected piping systems were developed, including a complete library of 3-D models for piping components.
- Study drawings for these piping systems were extracted from the 3-D models. In previous ship designs, considerable time was devoted to developing these drawings by hand or with 2-D computer drafting programs.
- By increasing the definition of the 3-D design to a greater level of detail, drawings become a natural by-product of the design effort; thereby enabling a significant increase in design productivity and quality.

To further improve the design process, NAVSEA is exploring new ways to use the 3-D models. Future plans call for integrating flow, stress, and dynamic response analysis software with the 3-D geometry models of the ship's piping systems to create a "smart" product model with all the necessary design data about the system. To further support this goal, NAVSEA continues to build data libraries of needed equipment and component such as pipe hangers, damage control and fire fighting equipment, and commercial fittings. In previous surface ship designs, the distributive systems have been an area of considerable uncertainty in terms of their effect on technical risk, ship weight and stability, and ship construction costs. The LPD 17 design team has made significant progress towards reducing these risks and uncertainties through use of a 3-D digital model of the ship's geometry.

To illustrate use of more detailed, lower level models, the following section provides a brief overview of their application to the design of the LPD 17's boat handling system is provided. In support of this effort, computer design tools were used to define and optimize the various crane and winch assemblies that are used to move the boats. A static model was used to integrate the dimensional interface requirements, identify interferences with other systems, and enable consideration of the human interface. Use of an integrated CAD 2 drawing database with its 3-D solid modeling capabilities allowed the design engineers to identify and resolve conflicts early in the design process.

Computer models of the boats kinematic and dynamic behavior were used to evaluate the ability of offshore crane designs to handle the 13m boats in sea state 3 or below. Boat kinematics were modeled using an interactive 3-D approach which also enabled input by fleet operators. This design tool simulated operation of the crane based on its performance characteristics (speed, articulation, rotation) and permitted viewing the boat handling evolution from the operator's cab, line handlers' positions, and safety officer's station. The interactive model will be available for use during initial training for the boat handling system.

A dynamic model was used to quantify the forces placed on the crane and lines when handling boats in sea state 3 taking into account the results of the seakeeping analysis for the specific hull form selected for the design. The results of this assessment were passed to several commercial crane manufacturers to enable them to determine if they had designs capable of handling these forces while remaining within the Navy's desired dimensional limits. By specifying system requirements in commercial terms, the

Navy hopes to eliminate the use of multi-tier military specifications and thereby reduce costs.

SA'AR-5. Perhaps the best example to date of the capability provided by three-dimensional computer-based design for a major warship is Ingalls Shipbuilding's SA'AR 5 Corvette Program. [Lindgren et al, 1992] The SA'AR-5 is an 86-meter, 1200-ton displacement combatant that Ingalls has called a "pocket cruiser." This ship is fairly advanced with combined diesel or gas turbine (CODOG) propulsion and advanced electronic systems.

Ingalls modeled the design process for the SA'AR-5 after their modular construction strategy and used a matrix organization to ensure a system level view. The "rows" of the matrix consisted of the ship's 15 design zones, each of which contained several construction assemblies. The columns of the matrix represented 14 different ship system and technical areas. The design zones and ship systems are identified in Table 18. A principal engineer was assigned to each of the technical areas; these engineers managed the analyses and development of systems within that specific area. Similarly, principal designers were in charge of design teams for each of the 15 design zones. The principal designers took the lead in resolving conflicts between the various technical areas within their zone.

Table 18. Design Areas Modeled in SA' AR 5 Development

Design Zones	Technical Areas
CIWS House	Naval Architecture and Ship Signatures
Forward Mast	Ship Structures
Pilot House	Weight Control
Stack	Outfit and Habitability
Aft Mast	Noise, Shock, and Vibration
Helo Hangar	Main and Auxiliary Machinery
Helo Deck	Deck Machinery
Steering	Piping Systems
Aft Machinery Room	Heating Ventilation, and Air Conditioning
Aft Engine Room	Ship and Machinery Control
Forward Engine Room	Electrical Power and Lighting
MCR SWBD	Command, Control, and Communications
Combat Information Center	Combat Systems
Sonar	Vendor and Government Furnished Information
Bow	

The design teams for the SA'AR-5 also comprised representatives from production planning, production engineering, shipyard craft supervision, and material sourcing, in addition to the engineers and designers. During the design process, producibility features such as basic manufacturing breaks, system routing, and machinery package boundaries were incorporated into the CAD models. As the design progressed, CAD models were sent to planning for a detailed definition of manufacturing units and work package definition.

Ingall's existing CAD/CAM system is the result of approximately 20 years of evolutionary development. The first computer-assisted design tools were developed in the 1960s, two-dimensional computer drafting was implemented in 1979, and the first three-dimensional product models were produced in the mid-1980s. Currently, the Ingall's CAD applications are processed on Hewlett Packard engineering stations on a local area network. This network is tied to an IBM 3090 mainframe host computer that processes the computer-aided manufacturing applications. Machine instructions to drive the numerical control are stored on IBM minicomputers and personal computers. These computers are also linked to the IBM mainframe so that all data can be passed electronically.

The key to fully exploiting a CAD system is for the many software applications required in the design and construction process to share a common product model database. For this project, Ingalls had seven major areas integrated with the CAD model database:

- The Ship Production and Design Engineering System (SPADES) is used to develop the three-dimensional geometric model for the structure.
- A Material Catalog, maintained on the CAD system in an ORACLE relational database system, validates part numbers and provides descriptive data for use on drawing parts lists.
- Material Requirements Planning tracks the validated material requirements for the product models.
- Pipe Bend System checks for producibiltiy, performs bend calculations and creates shop floor instructions.
- HVAC Fabrication System develops flat patterns, creates machine instructions, and provides shop floor control instructions.

- Electric Publishing System creates technical manuals using CALMA-created drawings.
- Integrated Logistics Support selects items for logistic analysis and establishes the initial logistics requirements.

Ingalls claims that the use of a three-dimensional CAD/CAM system for the SA'AR5 program resulted in a number of benefits. Although some of these benefits, such as improved interference checking, were expected and were the primary reason for implementing the system; the SA'AR5 program also realized several unexpected and equally important benefits.

Automated interference checking, the primary reason why the three-dimensional system was implemented, was a very powerful tool. The three-dimensional CAD system proved to be much more accurate than existing two-dimensional techniques and more accurate than physical mock ups (see Figure 14). The two-dimensional models can only check for interferences at selected planes and subjective judgment must be used to identify the interferences. Three-dimensional physical models are expensive to prepare and human error is often introduced in the translation from the drawings to the construction of the model. The three-dimensional CAD system, on the other hand, models objects at all points in space and automatically detects and reports interferences.

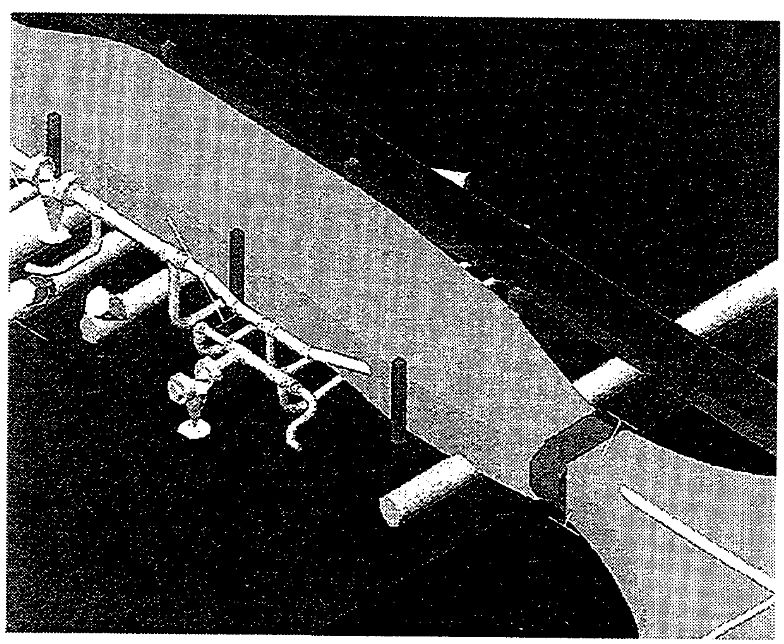


Figure 14. Illustration of Interference Checking Capability Provided by CAD System

An unexpected benefit of the three-dimensional CAD was improved work packages. Once the CAD model was built and interferences checked, construction drawings could be produced that represented work packages in the simplest and most efficient way possible. These packages could be tailored to contain only the information and material needed for a particular construction phase. With more conventional design techniques, the craftsman would have to pick his work off a large system-oriented drawing that contained unneeded data for his particular task and provided only a very limited number of views. Having an automated product model allowed separate drawings to be prepared for the smallest work packages and the largest block assemblies.

Computer aided manufacturing benefits naturally from the more complete product data models. The data bases needed to control the machines for steel and aluminum plate cutting, sheetmetal fabrication, and pipe bending were a byproduct of the computer aided design process.

Better communication among members of the design team was also an unexpected benefit. Unfinished CAD designs could be made available to the design team members more frequently than could be done with manual design methods. Additionally, the design process was more efficient by using libraries of common items (e.g., pumps and subassemblies) to eliminating redundant drafting work.

A final benefit that is difficult to quantify is greater customer visibility. Using visualization tools, the CAD models could be used to generate realistic representations of the ship. These visualizations allowed the designers to present the developing design to the customer. These visualizations are much more representative of the actual ship than are typical artist's renditions and they can be updated easily.

2. Simulation-Based Design

The Simulation-Based Design (SBD) Program is a DARPA-sponsored project that is developing and demonstrating the use of simulation technology in the design process. The program is using the concept of a Virtual Prototype, a prototype that exists entirely and exclusively on the computer, to explore the cost and time savings benefits that might be achieved in the design of complex mechanical systems. The virtual prototype will be able to operate realistically in "virtual environments," digital environments that can accurately mimic real-life atmospheric, oceanographic, geographic, electro-magnetic, and acoustic conditions.

The SBD Program is actively seeking to find what the technological state-of-the-art will provide and to identify where technological advances must be achieved. To determine these technological shortcomings, the program is using CAD product and process models to link and coordinate manufacturing, cost, performance, and life-cycle considerations throughout the entire life cycle of the product. The unique contributions of SBD are the use of advanced visualization methods, including virtual reality, and the emphasis on the inclusion of physics-based models in the CAD environment. The goal is to provide the designer, from concept development through detail design and beyond, with representations of the product that accurately simulate the total ship and systems in operation. The SBD Program predicts multiple payoffs from the program:

- Reduce design times by half
- Investigate advanced technologies "on-the-fly"
- Eliminate the need for physical prototypes
- Improve initial design and product quality

a. Phase I Results

The first phase of the SBD Program comprised a group of small scale demonstrations that sought to determine the potential of an SBD system and to identify the critical areas of development that are necessary to enable implementation. ARPA's Tactical Technology Office chose ship design as the theme for the initial demonstrations because of the complexity of that design task. The 18-month Phase I demonstrations sought to successfully implement simulation, integrated product and process development, and virtual prototyping for ships.

Phase I began in March 1993 with two contractor teams headed by the Electric Boat Division of General Dynamics and Lockheed Martin, respectively. The composition of these teams is shown in Table 19.

The two teams were able to provide demonstrations for a wide array of the classic steps in the design spiral. However, the designers perform these steps concurrently in the SBD environment instead of using the usual sequential and iterative approach. The SBD Phase I program provided explicit examples for the use of SBD in Requirements Specification, Concept Formulation, Collaborative Design, Training, Multi-Disciplinary Analyses, Manufacturing, and Life Cycle Costs.

Table 19. Phase I SBD Participants

General Dynamics, Electric Boat	Lockheed Martin
Deneb Robotics	Newport News Shipbuilding
Intergraph	Science Applications International Corp.
Loral Federal Systems	Fakespace
Parametric Technology	
Silicon Graphic	
University of Iowa	
University of North Carolina	

Requirements. SBD used a continually evolving Product and Process Model (PPM) to provide information on the ship design to distributed analysis tools in the Phase I analysis. In a fully developed SBD Architecture, the level of detail provided by the PPM to the analysis tools will be consistent with the stage of design. During feasibility studies, for example, generic powerplant data such as peak horsepower and average fuel consumption might be sufficient. However, during a simulated training exercise, generated noise, heat emission, and fuel consumption for a given power setting might be required. For Phase I, only analysis programs that examine completely defined systems were implemented.

The Phase I demonstrations performed trade-off assessments of conceptual systems. In particular, a new mission was added for a proposed ship. This new mission led to assessments of which candidate ships would best meet the new requirements. After the candidate ship was selected, the optimum power requirements were calculated and an approximate size diesel engine was selected.

Concept Formulation. SBD used a number of demonstration efforts to show the capabilities of a fully developed PPM. These demonstrations emphasized that an object in the PPM was much more than a geometric picture of the object. Objects in the PPM carry information of their role in the ship, their relationships to other objects in the PPM, the design constraints they must follow, and the functionality they provide. Four prototype technologies were demonstrated that play a strong role in concept formulation and early design:

- Smart Catalog and PPM Update - During the Phase I demonstration scenario, the power requirements for the ship were increased. This increase required a different diesel engine. During the demonstration, a member of the Integrated Product and Process Development team accessed a diesel manufacturer's

catalog on the Internet using a World Wide Web browser. From this catalog, the designer selected an appropriate diesel and inserted it into the PPM. When this new diesel was added, the PPM updated all of the requirements of associated systems. In the example, the requirements for a new heat exchanger were calculated and a new heat exchanger was selected over the Internet and was brought into the PPM.

- PPM "Rubber Banding" - PPM "rubber banding" was prototyped in the Phase I demonstration. With rubber banding, if an object is moved, all associated connections to that object (e.g., fuel and electrical lines) are also moved and updated. This shows, for example, that a pipe is not merely a cylindrical drawing object in the PPM, it is a logical object whose function is to connect from one specified point to another.
- Ductwork Routing and Re-sizing - Again to emphasize that the PPM carries much more than geometric data for objects, a piece of piping was moved in the Phase I demonstration and the dimensions of the pipe changed appropriately to maintain constant volume.

Human Computer Interfaces. SBD is investigating the usefulness of immersing designers, engineers, craftsmen, and trainees in virtual environments with the PPM. The Phase I work investigated a variety of Human Computer Interfaces as well as additional cues that would be needed to allow the user to move through and be aware in the virtual environments. This was shown to be a technology area that requires advancement.

Collaborative Design. The Defense Simulation Internet was used to conduct simulated operations of the virtual prototype. In the DARPA demonstration, a tank driver at a remote site used a simulator to drive his virtual vehicle onto the virtual ship. In this demonstration, the operators noticed that at several times the tank's treads penetrated the ship's ramp. The need to conduct interference (or contact) checking in three spacial dimensions as well as in time stretched the capabilities of the current DSI.

Training. By adding virtual reality tools to the PPM, training can be conducted on the prototype prior to its ever being built. The demonstrations showed two training scenarios—a fire fighting exercise and a diesel engine start-up—to display the potential of this capability. In the fire fighting exercise, a person was fully immersed in the virtual environment and performed the necessary procedures to extinguish the fire. In the engine start-up demonstration, an anthropomorphic model simulated the start-up procedure to test the ergonomics and accessibility of the engine room.

Multi-Disciplinary Analysis. This demonstration tied computer aided engineering models to the PPM. The particular demonstration combined an ocean hydrodynamic model, a structural analysis model, and the PPM to provide the designer with real-time hull stresses in response to pressures from the virtual ocean environment.

Manufacturing. Phase I completed a rudimentary manufacturing analysis. The analysis sought to provide rapid feedback on the impact of design changes to the conceptual system on the schedule and cost of the virtual ship.

Life Cycle Cost. One of the elements of the PPM that is constantly being updated is the cost. The system includes the entire life cycle costs of the product and the contributors to the cost. As the design matures, the cost becomes more precise.

b. Phase II Results

Phase II of the SBD project began in fiscal year 1995 with the selection of Lockheed Martin as the SBD Prototype System Integrator. As the Integrator, Lockheed Martin will:

- Develop an SBD architecture
- Demonstrate the architecture
- Identify required technology developments
- Locate potential candidates for the technology developments
- Manage and integrate the work of technology and application developers.

The program is focused on developing a core architecture. This core architecture rests on high performance networking services, user interfaces and tools, methodologies and supporting software for distributed collaboration, and intelligent, distributed database structures. To fully test the candidate architecture, the virtual prototype for the Phase II demonstrations will be a generic surface combatant. Critical technical areas that the Phase II analysis may address are:

- Visualization and sensualization of data
- Tactile feedback
- Object oriented database management
- Data standards
- Information baselines for distributed environments

- Wide area network bandwidths
- Multi-level security
- Information technology.

The primary integrator is expected to focus on those critical areas that best complement the overall SBD program and to integrate those technologies into the core architecture.

3. Other Efforts

In addition to the SBD program, several other efforts are underway that will provide useful insights to the ship design process. Two efforts that may play a large role are DARPA's MARITECH Program and work at the Massachusetts Institute of Technology that is seeking to logically coordinate and sequence complex design processes.

a. MARITECH Program

DARPA, in consultation with the Maritime Administration and the Navy's Office of Naval Research, is managing a five-year MARITECH Program. MARITECH is an effort to develop and apply advanced technology to improve the competitiveness of the U.S. shipbuilding industry. MARITECH matches industry investment with federal funds to develop and implement technologies and advanced processes for the competitive ship design, marketing, construction, and support. These technologies and processes will be applied to Navy combatants, resulting in improved ship performance and more affordable ship acquisition for the U.S. military. The goals of the MARITECH program are to:

- Preserve the shipbuilding industrial infrastructure
- Ensure affordable Navy ship construction by using world-class processes and technologies
- Facilitate the U.S. shipbuilding industry's reentrance into the commercial market.

The FY 1995 MARITECH competition selected 24 projects that are listed in Table 20, Advanced Shipyard Process and Shipboard Technology Development, and Table 21, Near-Term Ship Design and Construction Technology. These projects include efforts to advance shipyard process and product technology and to give the shipyards design experience. Particularly important to furthering shipyard automation tools are the

STEP-Ship Product Model (at $9,760,000), the Process Tools for Shipyard Construction, Conversion, and Repair (at $4,890,000), and the Automated Welding of Structural Beam Erection Joints (at $2,490,000). Combined, these three projects account for approximately 30 percent of the money being spent for Advanced Shipyard process and Shipboard Product Technology Development. All of the projects in the Near-Term Ship Design and Construction Technology category represent an effort to strengthen design capabilities and, presumably, automated design capabilities as well.

Table 20. Advanced Shipyard Process and Shipboard Product Technology Development (BAA #94-44)

Project and Proposed Cost	Consortium Members	
Adaptive Control for SLICE and SWATH Ships - $960,000	Lockheed Missiles & Space Company, Inc.	Pacific Marine, Inc.
Panel Line Welding - $4,700,000	Babcock and Wilcox A&P Appledore CIM Systems	Ogden Engineering Corp. Staubli IHI Co. Ltd.
SWATH High Speed Ferry - $900,000	SWATH International Altair Engineering, Inc.	Bollinger Shipyard
Advanced Material Technology - $7,760,000	UC - San Diego USCG NASSCO SWATH Ocean Systems Trans-Science Corp.	Giannotti Marine Services TPI, Inc. Structural Composites Inc. Harley Boat Co. Designers and Planners
Design of the Stern Factory - $3,560,000	McDermott Shipbuilding, Inc. Intergraph Corp. U Michigan TRI	Man B&W Diesel McDermott Shipyards Babcock & Wilcox
Automated Welding of Structural Beam Erection Joints - $2,490,000	CYBO Robots, Inc. Bath Iron Works NASSCO	Avondale Edison Welding Institute ARM Automation, Inc.
High Power Waterjet Propulsor - $2,790,000	Bird-Johnson, Inc. General Electric	Mercer Management Consulting, Inc. Band-Lavis & Associates
Test Plan American Underpressure System - $2,240,000	MH Systems, Inc. West Coast Shipping, Co.	Beth Ship Sabine Yard Naval Command, Control Ocean Surveillance
ISIT Platform - $3,830,000	Marine Management Systems, Inc. Sperry Marine, Inc. General Electric Marine Systems and Service	ABS Marine Services, Inc. M Rosenblatt & Son, Inc. Radix Systems, Inc. UltimatEast

Table 20. Continued

Project and Proposed Cost	Consortium Members	
Composite Ship Superstructure - $1,880,000	Structural Composites, Inc., Glasforms, Inc., Naval Sea Systems Command, FRP Technologies, Compsys American Bureau of Shipping, Naval Surface Warfare Center - Carderock, Interplastic Corporation	Ingalls Shipbuilding Reichhold Chemical Baltek Corp. Bedford Reinforced Plastics Advanced Textiles Inc. Owens Corning Fiberglas Fiber-Tech Industries, Inc.
STEP-Ship Product Model - $9,760,000	Intergraph, Bath Iron Works General Dynamics/Electric Boat	Ingalls Shipbuilding, Inc. Newport News Shipbuilding, Inc. Advanced Management Catalyst,
Vessel Optimization and Safety System (VOSS) - $2,000,000	Sperry Marine, Inc.	Ocean Systems, Inc.
SMARTBRIDGE - $5,840,000	Martin Marietta RPI	NOAA Chevron
Focused Technology Development Project for a New LNG Containment System - $5,990,000	Marinex International General Electric Co.	Metro Machine Corp., Inc. Energy Transportation Group
Process Tools for Shipyard Construction, Conversion and Repair - $4,890,000	CTA, Inc.	Honolulu Shipyards, Inc.

Table 21. Near-Term Ship Design and Construction Technology (BAA #95-02)

Project and Proposed Cost	Consortium Members	
"City Slicker" - $1,100,000	Peterson Builders, Inc. Spirit Cruises, Inc.	FBM Marine Group
"Reefer 21" - $1,300,000	Bender Shipbuilding and Repair Colton & Company	Columbia Group, Inc. Nordvest Consult AS
Fast Ferry Market Penetration - $610,000	Nichols Brothers Boat Builders Gladding Hearns Shipbuilders	Incat Designs Sydney
Midfoil SWAS Ship Design - $1,530,000	Pacific Marine Nichols Brothers Boat Builders	Westport Shipyards Art Anderson Associates
Handy Size Bulk Vessels - $6,270,000	Alabama Shipyard, Inc. Mitsubishi Heavy Industries	Tritea Maritime, Ltd.
LNG Carrier - $7,850,000	Newport News Shipbuilding Exxon Co.	IHI Shell International Shipping
Large Fast Ferry Technical Development - $5,040,000	Halter Marine, Inc. Bank of Tokyo Financial Corp. V. Ships (USA) Inc.	Band Lavis & Associates Derrick Offshore Fry Design & Research
Shallow Draft - Self Loading/Unloading Cargo Ship Design - $8,000,000	Vibtech, Inc. SENESCO Rhode Island Technology	AFL/CIO Metal Trades Department Kvaerner Masa Marine, Inc. NSWC-Carderock
High Speed Monohull Contract Design Project - $3,010,000	Bath Iron Works General Electric	American Automar Kvaerner Masa Marine

b. Design Structure Matrix

Modern design principles suggest that the design process itself as well as the product being designed should be re-examined. A common phrase heard describing an ideal design procedure is "concurrent engineering." In concurrent engineering, an interdisciplinary team approach is taken for the design process. Specialists from several technical disciplines as well as from non-technical areas such as operations and marketing, are all involved from the start in the design process. In this way, areas that are far downstream in the product development path, such as manufacturing, can influence the initial design and help to produce a better project. The concept of concurrent engineering has helped to bring better products to market faster, because tradeoffs are resolved quickly and rationally and design and production issues are considered simultaneously.

However, many of the successes in concurrent engineering have been with relatively small design teams. A team led by Professor Steven Eppinger at the Massachusetts Institute of Technology has been studying the principles that underlie success in small scale concurrent engineering in order to identify and apply these fundamentals to more complex design problems "in the large." [Eppinger et al, 1994]

Professor Eppinger's team has identified four characteristics of concurrent engineering in the small. The first of these is that the design teams comprise a cross-disciplinary team of approximately 5 to 20 people who are empowered to make design decisions. These teams feature what are called "high-bandwidth" technical communication. The teams work in close vicinity, either physically collocated or electronically connected, and can transfer information back and forth with a minimum of formality. Tradeoffs in competing design areas are resolved by mutual understanding. The teams are small enough and work closely enough together that these tradeoffs can be accomplished to produce the best overall design. Finally, design and production issues are considered simultaneously. This helps to increase the producibility and quality of the project.

Concurrent engineering in the large tries to achieve the same ideals as the small design project for a much more ambitious project. In a large design problem, the project is decomposed in many small projects. These small projects function as a network of teams. In theory, each of these smaller teams can function via the same paradigm as concurrent engineering in the small, but the challenge remains to integrate these separate projects into a total system solution. Many attempts at concurrent engineering in the large

have mistakenly acted as though concurrent engineering is simply gathering the right team together. Eppinger's work has shown that a major element that is required for concurrent engineering to work for large projects is the understanding of the interactions among the sub-projects in the decomposition. Eppinger's team has taken a systematic approach to the design process and is now developing a tool called the Design Structure Matrix.

The Design Structure Matrix (DSM), first proposed by Steward [see Steward, 1981] is a powerful tool in identifying the optimum sequence of tasks in a complex design process as well as critical areas that dominate the design timeline. Basically, the Design Structure Matrix begins by making a list of all the design tasks (the sub-projects mentioned above). These tasks become both the row and column headings for a large matrix as is shown in Figure 15. Next, the manager using the DSM queries the leader of each of the sub-projects to determine from which other sub-projects each needs information. If a sub-project, or task, requires information from another, a mark is placed in the column corresponding to the input task. In this way, the entire matrix is populated. Once the matrix has been completed, an analysis is performed to find a sequence of the design tasks that makes the DSM lower triangular in form (i.e., no marks are above the diagonal elements of the matrix).

In general, this goal of a lower diagonal matrix form cannot be achieved. Those rows whose elements lie behind the diagonal represent tasks that are either independent of directly preceding task or dependent on preceding tasks, but they are not dependent on information from any following tasks. Rows with elements in columns to the right of the diagonal represent interdependent tasks. The independent task can be conducted in parallel and the dependent task can be conducted in series. Neither type of task would necessarily benefit, however, from concurrent engineering teams; these tasks are "stand-alone." The interdependent tasks much be solved iteratively. It is these projects that gain the most from concurrent engineering philosophies.

TASK		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Performance Requirements	1	•													
Weapons Analysis	2	X	•												
Sensor Analysis	3	X		•											
Develop Evaluation Criteria	4	X			•										
Feasibility Study	5	X	X	X		•									
Select Promising Solution	6					X	•							X	
Complete Configuration	7						X	•		X					
Analyze Utilization and Vulnerability	8							X	•						
Synthesize Optimum Solution	9								X	•					
Analyze Manning	10							X			•				
Operation Costs	11										X	•			
Evaluate Acquisition Costs	12						X						•		
Evaluate Configuration Effectiveness	13									X		X	X	•	
Approve for Preliminary Design	14													X	•

Figure 15. Illustration of Design Structure Matrix

Figure 16 shows the three possible sequences for a project consisting of two design tasks. The first example shows a dependent sequence; the problem must be solved in series with task b following the completion of task a. The DSM for this sequence shows that no marks lie above the diagonal of the matrix. The second example shows independent tasks that can be performed in parallel. As in the first example, the DSM has no marks above the diagonal. In fact, only diagonal elements exist for this DSM. Here, both tasks are equivalent. Finally, the third example shows interdependent tasks that must be solved iteratively. The DSM for this sequence is fully populated and represents a complex design problem.

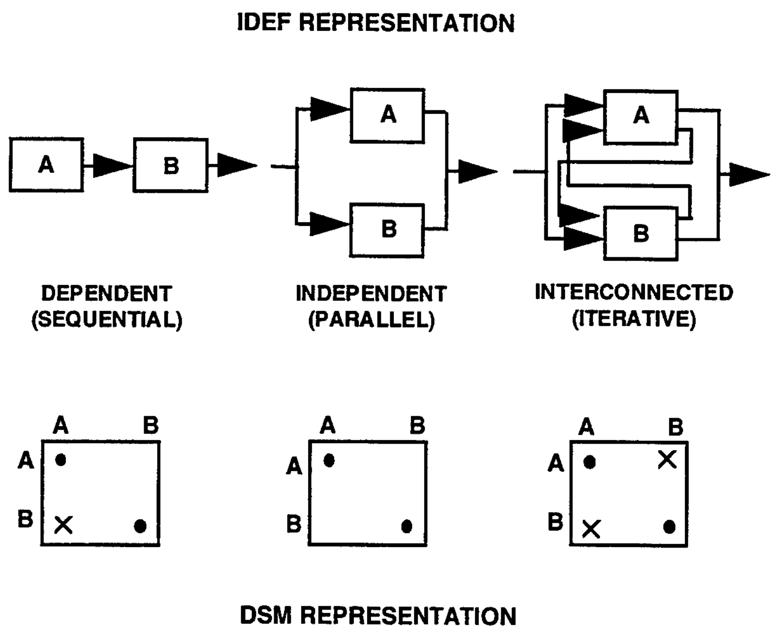


Figure 16. Possible Sequences for a Project With Two Design Tasks

The DSM has highlighted an often overlooked aspect of concurrent engineering; the increased coupling strategy of concurrent engineering and of design for manufacture can greatly slow product development. The DSM attempts to show which portions of a project should be attacked concurrently and which are best left to specialized design teams. This methodology systematically demonstrates those problems that are best solved by a team approach.

The DSM has several advantages over other sequencing tools. PERT, for example, is very good at identifying critical paths in a design sequence, but it is unable to represent coupled tasks. Coupled tasks must be collapsed into a single task for PERT; the project appears simpler, but real design problems can be hidden and made more difficult to diagnose and solve. Integration Definition for Functional Modeling (IDEF) methodologies can represent coupled tasks, but they are less amenable to automated improvement. Eppinger claims seven advantages of implementing a DSM:

- Documents existing procedures for scrutiny
- Resequences and regroups design tasks to reduce complexity
- Shares engineering data earlier and/or with known confidence
- Redefines critical tasks to facilitate overall project flow

- Exposes constraints and conflicts due to task interactions
- Helps design managers to place emphasis on task coordination
- Allows design iteration to be strategically planned

Eppinger has extended the basic "binary" representation of the DSM by explicitly including measures of the degree of dependence and of task duration in the cells of the matrix. The numerical metrics are used to quantify the dependence between tasks to reveal strong and weak links. These metrics are then used to assign an overall metric to the matrix called the "iteration score." Automated search techniques can then be used to find the sequence of tasks that yields the best iteration score.

The DSM has been used to better understand and improve existing design cycles. NASA used the process to model the design of a complex spacecraft antenna system with over 50 interrelated tasks [Padula et al, 1988]. The DSM analysis showed that for this design problem there were a small number of large subsystems with 5 to 20 tasks each. These coupled groups of tasks could then be performed in sequence.

Eppinger has used the DSM methodology to help determined the composition of product development teams for the design of a "new-generation" engine. The engine design problem was decomposed into 22 product development teams (e.g., engine block, cylinder heads, pistons). Each of these PDTs operated on the concept of concurrent engineering in the small. The task was to determine how these PDTs should interact to achieve concurrent engineering in the large. The DSM was used to identify five system teams and to identify those team members who should belong to more than one team.

As a result of analyses and applications of the Design Structure Matrix, Eppinger has suggested a plan for how others might implement the methodology to improve the design process:

- Engage designers and engineers in a development process modeling activity.
- Sequence the tasks to minimize unnecessary couplings.
- Divide the coupled areas of the DSM into appropriate subtasks.
- Facilitate design iteration in the coupled tasks with improved automation tools and correct design team composition.
- Perform as many tasks in parallel as possible.
- Remove less important couplings that might cause wasteful iteration.

- Carefully examine couplings that may lead to long iteration time.
- Continuously modify and improve the DSM.

The benefits of the design structure matrix methodology are two-fold. Even if the design process is not modified, using the matrix can provide a useful display of the current design sequence and can highlight those couplings in the current process that dominate the design cycle time. Design cycle times in this case could be reduced by ensuring that higher quality information is passed into the iterative design task so that the number of iterations will be reduced. If the design team is more flexible, the resequencing algorithms can be used on the DSM so as to reduce the number of coupled tasks.

F. FINDINGS

The Navy has experimented with several different design strategies since 1950. One principal has been consistently followed, however: NAVSEA (formerly BUSHIPS) has retained firm control of the design process. Even during the TPP era, the Navy ended up taking charge of the design process during contract execution in order to correct significant design inadequacies.

Two significant innovations, introduced in the 1990s, promise to have a lasting effect on the Navy's design strategy. The first of these is the Navy design, acquisition and construction (DAC) improvement program initiated by the Chief Engineer in 1991. The second is the Product-Oriented Design and Construction (PODAC) working Group organized in 1993 for the design of the LPD 17.

One of the purposes of the DAC program is to get advice on "where to look first" in order to effect real savings in ship life cycle costs. Design represents only 2 percent of the life cycle cost for a typical Naval ship. However, it is estimated that more than 80 percent of total costs are determined before the completion of contract design. It is therefore important that the process gets off to the right start during the design phase. DAC was also the formal introduction of Concurrent Engineering to the U.S. Navy design process.

PODAC was the first full scale application of the concept of concurrent engineering to a Navy ship, the LPD 17. The LPD 17 is the first Navy ship to be metric, commercial standards are to be used, and producibility is a key objective of the design team. It is too early to know the final outcome of the LPD 17 design strategy, but it is

clear that the Navy is attempting to introduce many innovations into the design and management of the production of the ship. These should be closely monitored.

The PODAC concept is being extended to three surface ship programs currently in the planning stage. These are the SC 21 combatant, the ADC(X) point-to-point resupply ship and the Arsenal Ship. Concurrently NAVSEA is proposing a different design strategy wherein Preliminary and Contract design are combined into a two part Contract Design phase which extends from Milestone I to Milestone II. (See Figure 17.) The first half of contract design would be devoted to engineering development and the second half to producing a bid package. Contract design would be accomplished by two competing industry teams both of which include representation from the Navy. Following Milestone II approval, issuance of an TFP, evaluation of bids, and source selection, the winning yard or consortium would be authorized to commence detail design and construction. Such a system would eliminate the Generic Build Strategy in favor of a Build Strategy chosen by the winning yard. In the case of the ADC(X) (essentially a commercial cargo ship), the PMS is investigating commercial acquisition procedures with the intent of acquiring the ships using a COR in accordance with standard commercial practice. All of the proposals for these ship programs appear to offer significant improvement in the Navy's ship design strategy.

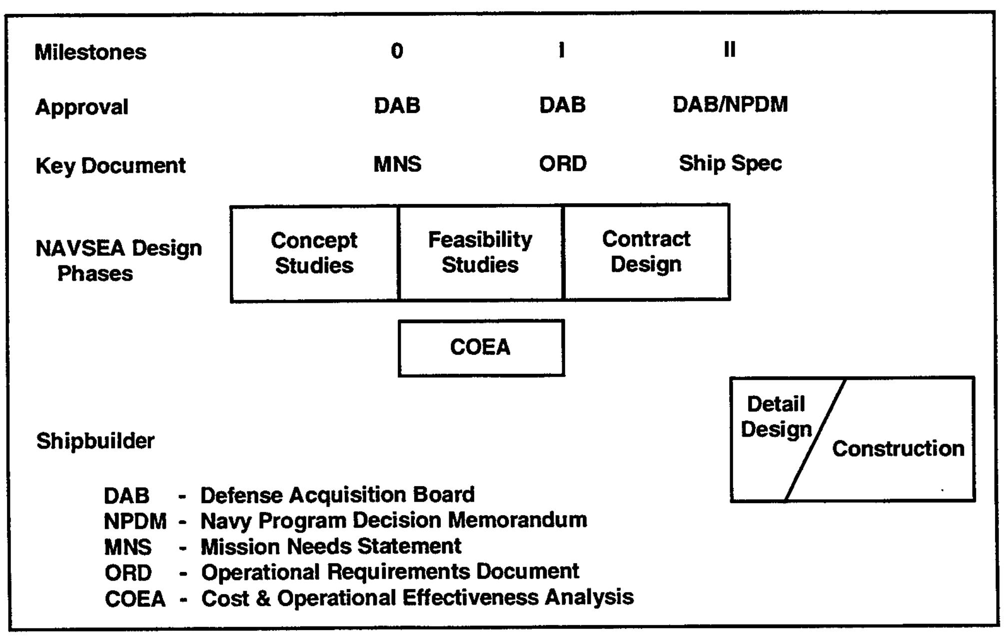


Figure 17. Alternative Navy Ship Design Process

The Navy has, during the past two decades, attempted to involve the shipbuilders early in the design phase. However, concurrent engineering goes much further than just the shipbuilder; other important stakeholders must also be brought into the design process. The operators, support personnel, combat and support systems developers, and suppliers also have a stake in the design. In order to realize the benefits of a true systems engineering approach, all of these stakeholders are represented in the LPD 17 design as part of the Integrated Product and Process Development Team.

To help ensure that ship design will be compatible with the production facilities and methodologies of the yard that will build it, the Navy is currently developing a Generic Build Strategy. Strong points of the GBS appear to be in producibility and the hull block planning during preliminary design. This is the time in the design process when the Navy can lay the ground work for introducing incentives and guidance for accuracy control and utilization of ATC. One negative aspect of the GBS, as presented, is that it may go on too long. Preliminary design is systems oriented, but during contract design the design team must transition to a zone orientation. At this point the design must be more responsive to the shipbuilder's production facilities and processes, and to teaming arrangements with suppliers. Long lead time material and integration of the weapons system are also important issues since many long lead time items generally must be ordered during contract design.

The linking of design with production through an advanced CAD/CAM system is essential to implementing concurrent engineering and group technology ship production. All of the major Naval shipbuilders are investing in CAD/CAM. However, the effectiveness of these efforts is reduced by the lack of a single standard, or NAVSEA universal interpreter.

REFERENCES

1. Advanced Marine Enterprises, *LX Preliminary Design (PD) Generic Build Strategy Study*, NAVSEA Tech. Note No. 070-03R3-TN-0012, Department of the Navy, Naval Sea Systems Command, Arlington, VA, April 1994.
2. Andrews, David, *The Management of Warship Design; The MOD Warship Project Manager's Perspective*, Royal Institute of Naval Architects Proceedings, April 1992.
3. Ball, William B., *DoD Acquisition Policy and the Effect of Naval Ship Design*, SNAME/ASE Ship Design Symposium, February 25, 1992.
4. Billingsley, D.W., J.D. Arthurs, K. Rambhala, and W.R. Schmidt, *Revolution at NAVSEA, Managing Design and Engineering Information*, SNAME/ASE Ship Design Symposium, No. 14, February , 1992.
5. Carpenter, LCDR John D., USN and LCDR Peter C. Finne, USN, "Navy Ship Procurement," *Naval Engineers Journal*, December 1972 (69-81)
6. Chirillo, L.D. and R.D. Chirillo, "The History of Modern Shipbuilding Methods: The U.S.-Japan Interchange," *Journal of Ship Production*, Vol. 1, No. 1, February 1985, pp. 1-6.
7. Chirillo, L.D. Comment on Lamb, T., A. Allan, J. Clark and G. R. Snaith, *A Review of Technology Development, Implementation, and Strategies for Further Improvement in U.S. Shipbuilding*, SNAME Annual Meeting, Washington, DC, October 4-7, 1995.
8. Christensen, Walter L. and Philip C. Koenig, "Standard Outfit Packaging Units in the LPD 17 Ship Design: A Production Impact Study," *Journal of Ship Production*, Vol. 11, No. 4, November 1995.
9. Clausing, Don, *Total Quality Development A Step-By-Step Guide to World Class Concurrent Engineering*, ASME Press: New York, 1994.
10. Collins, CAPT John T., "USS Spruance (DD 963) Class, Designed for Change-- The Payoff is Now," *Naval Engineers Journal*, April 1975.
11. Department of the Navy, "Total Quality Management (TQM) Awareness Seminar," 1 October 1989.
12. Eppinger, S.D., E.D. Whitney, R.P. Smith, and D.A. Gevala, *A Model-Based Method for Organizing Tasks in Product Development*, (1994) 6: 1-13.
13. Hammon, Colin and David Graham, *Disruption Costs in Navy Shipbuilding Programs*, Center for Naval Analyses, Alexandria, Virginia, Study Report CNS 1149/April 1980.

14. Horne, RADM R. B. Jr., *NAVSEA Ship Design, Acquisition and Construction Process Improvement Project: Workshop II,* Naval Sea Systems Command, 6-7 May 1991.

15. Huthwaite, Bart, *Strategic Design: A Guide to Managing Concurrent Engineering*, Institute for Competitive Design, 1994.

16. Keane, R. G. Jr., B. F. Tibbitts, and T. A. Beyer, *From Concept to Commissioning: A Strategy for the 21st Century*, SNAME/ASNE Ship Design Symposium, February 1992.

17. Lindgren, J.R. Jr., W.A. Solitario, A.P. Moore, and M.A. Streiff, "CAD/CAM Goes to Sea: The SA'AR-5 Design and Construction," *Naval Engineers Journal*, May 1992.

18. Nagel, Roger and Rick Dove, *21st Century Manufacturing Enterprise Strategy: An Industry Led View*, Vol. I and *21st Century Manufacturing Enterprise Strategy: Infrastructure*, Vol. II, Iacocca Institute, Lehigh University, Bethlehem, PA, 1991.

19. National Shipbuilding Research Program, *Assessment of Computer Aids in Shipyards*, April 1993.

20. Padula, S.L., C. Sandridge, R.T. Haftka, and J.L. Walsh, *Demonstration of Decomposition and Optimization in the Design of Experimental Space Systems*, Recent Advances in Multidisciplinary Analysis, NASA Langley Research Center, Hampton, VA, 1988, pp. 297-316.

21. Paulus, Christopher, *Commercial Ship Acquisition*, PMS 325 Viewgraph Presentation, June 1995.

22. Perry, William J., *Acquisition Reform*. Secretary of Defense Memorandum 15 March 1994

23. Ranson, G. N, *Group Technology: A Foundation for Better Total Company Operation*, McGraw-Hill, London, 1972.

24. Ryan, J. Christopher (Kit) and Otto P. Johns, *Improving the Ship Design, Acquisition and Construction Process*, Association of Scientists and Engineers 28th Annual Technical Symposium, 11 April 1991.

25. Steward, D.V., *The Design Structure System: A Method for Managing the Design of Complex System*, IEEE Transactions on Engineering Management, Vol. EM-28, No. 3, August 1991, pp. 71-74.

26. Stewart, J.M. and A.J. Haskell, *Can Technology Revitalize Our Shipbuilding Base*, Society of Naval Architects & Marine Engineers, October 1995.

27. Tibbitts, B. F. and R.G. Keane, Jr., "The Warship Design Process: Making Design Everybody's Job," *Naval Engineers Journal*, May 1995.

28. Tibbitts, B. F., R. G. Keane, Jr., and R. J. Riggins, "Naval Ship Design: Evolution or Revolution?", *Naval Engineers Journal*, May 1988.

29. Tibbitts, B. F., R. G. Keane, Jr., P.M. Covitch and E. N. Comstock, *Naval Ship Design in the 21st Century*, SNAME Transactions, 1993.

30. Tibbitts, B. F., R. G. Keane, Jr., *Shipbuilder Participation in Early Design Stages*, SEA 03D5 Slide Presentation, May 1994.

31. Tibbitts, B.F., Personal Correspondence, 28 February 1996.

32. Wilkins, James R. Jr., Perry Singh, and Todd Cary, *Generic Build Strategy-Preliminary Design Experience*, The Society of Naval Architects and Marine Engineers 1995 Ship Production Symposium, January 25-27, 1995.

This page intentionally left blank

III. SHIP PRODUCTION

As indicated in the discussion of ship design practices, the Navy's Product-Oriented Design and Construction project, concurrent engineering and the generic build strategy provide a model for naval ship design and production in the 1990s. However, ship production is different from design in at least two important ways. The cost and efficiency of production methods are determined by market forces in both the product and resource markets. Additionally, production is primarily the province of industry. The government can recommend the adoption of specific practices, and can write controls intended to encourage production efficiencies into shipbuilding contracts. However, in the final analysis, the shipbuilder will choose an investment policy and production process based on economic factors and its own shipbuilding strategy.

This is not to say, however, that the yards have exclusive province over ship production. The Navy, to a certain extent, reserves part of production to itself through the retention of direct control over long lead items and the development and procurement of weapons systems. And lastly, because the Navy must deal with a very diverse industry in a competitive manner, the Navy wields direct control through ship specifications and contract clauses, such as directed changes. These controls are important and set U.S. Naval ship production apart from commercial practice.

Naval ship production has developed as a hybrid system, with the major ship contractors somewhere between private entrepreneurs and Navy utilities. Eight U.S. shipyards currently have contracts for Naval ships. Six major yards produce the bulk of Navy surface ships and all submarines. One of these yards--Electric Boat--builds only submarines. For the past two decades, these yards have been almost completely isolated from the world shipbuilding market. Except for some limited work, such as floating prisons, hydro-electric plants and foreign combatants, the Navy has been their only customer. Consequently, they have developed business and build strategies, and production processes that are responsive to the Navy.

A major effort is currently underway to assist the U.S. shipbuilding industry in entering the world market. The Navy sees this as a way of distributing overhead costs and

investment in more efficient technology among other customers. However, with a few rare exceptions, the Navy has not indicated a desire to relinquish any degree of control over the production process in order to accomplish this. Neither have all of the major Navy ship producers indicated a desire to change their way of doing business in order to enter the world market. These yards are in a niche market that currently suits their business objectives. At issue is whether the Navy can afford to support an archaic acquisition system, albeit one that is solely responsive to its needs, and whether this is really the best alternative for the United States, taking into account both economic and national security considerations.

The chapter is organized into five sections. Section A summarizes trends and practices in ship production, and describes the economic and political factors that contribute to current production practices. Although some of this information duplicates material in Chapter IV, it is presented here to help relate ship production to the overall industrial performance of the shipbuilding sector. Section B describes how production is affected by Navy management and contracting practices and thus ties production to the government's acquisition strategy. Section C examines productivity and shipbuilding technology in U.S. yards, and compares U.S. yards with foreign yards. Section D describes several important Navy and yard production-related initiatives and discusses their potential benefits. Findings are summarized in the chapter's final section.

A. FACTORS INFLUENCING PRODUCTION

Ship production practices are driven by diverse political factors as well as the product and resource markets. Shipbuilding in the United States is essentially a closed system, dependent on a single buyer, the U.S. government. Since the 1980s, when differential subsidies were discontinued, the Navy and operators of Jones Act ships have been the only customers for ocean going ships.[1] Between 1987 and 1994, orders for commercial ships of 1000 gross tons or greater awarded to U.S. shipyards amounted to only eight ships.

There is some indication that the Title XI loan guarantee is having a significant effect on the U.S. shipbuilding market. In 1994 and 1995 Newport News contracted with

---

1 The Jones Act reserves Cabotage trade (trade between U.S. ports, including U.S. possessions—Puerto Rico, U.S. Virgin Islands, and Guam) to ships built in the US.

Eletson shipping to build four Double Eagle product tankers under Title XI loan guarantees. These were the first orders placed in a U.S. shipyard by a foreign ship operator since 1960. As of November 1995 orders pending for construction in U.S. yards included 26 ocean going commercial vessels contingent on Title XI financing guarantees, with options for nine more. Twenty of these vessels are for foreign operators. Including these 26 vessels, total commercial orders pending for ocean going vessels, ferries, jack-up vessels, barges and excursion boats, as of November 1995, totaled $3,637 million. This compares with a total of $4,589 million in orders pending for U.S. military and MARAD ships. [Marine Log, Nov. 1995]

1. Product and Resource Markets: Market Cyclicality

Swings in demand for ships characterize both the world and domestic markets. World market cycles follow both economic and international political stimuli. Between 1970 and 1975 world deadweight tonnage (dwt) increased by 70 percent. With the oil embargo of 1973 the market contracted dramatically, and the world order book decreased from 242.3 million dwt in 1974 to 32.0 million dwt in the first quarter of 1979. Much of the tonnage built in the early 1970s is due for replacement, and some forecasters project that expanding world shipping business indicates another shipbuilding boom over the next 5 to 7 years. [Peters, 1993] Other forecasters are more guarded in their predictions.

The domestic U.S. market has also experienced major cycles associated with the economy, but the primary market driver since the early 1980s has been political. The U.S. orderbook for commercial ships of 1000 gross tons or greater dwindled from 62 in 1980 to zero in 1988. Concurrently, the Navy ship acquisition program reached its largest size in peacetime history as the Navy built toward a 600-ship fleet. Since 1991 the Navy program has gone from 82 ships of 1000 light displacement tons (ldt) or greater on order or under construction to 57 as of December 1994. Eighteen of these are scheduled for delivery in 1995. The current Navy shipbuilding program calls for delivery of nine or fewer major ships per year for the remainder of the decade.

As a major trading nation and world power, the United States has had as national policy the maintenance of a shipbuilding industrial base capable of expansion in time of war. This policy has kept the industry alive, but not necessarily healthy. Government-induced demand has been highly uncertain, particularly since the 1980s when major subsidy programs were discontinued. Overlaid on this is the current downsizing of the

Navy. The uncertainty of the market has resulted in industry risk aversion policies, such as labor intensiveness. The labor force can be reduced rapidly, whereas capital, once in place, represents a near constant cost regardless of utilization. Labor intensiveness is efficient from the viewpoint of the individual producer, but not necessarily from the standpoint of efficient utilization of national resources.

2. The Shipyard Labor Market

Past national policy has resulted in the isolation of the shipbuilding industry from the world market. This has resulted in a low technology, labor-intense high-cost industry. With the discontinuation of subsidies and drawdown in the Navy, U.S. policy has also resulted in a contracting industry. In 1994 the Major Shipbuilding Base (MSB), as identified by MARAD and the Navy, consisted of 21 privately owned shipyards. The MSB is defined as those privately owned yards that are open and have at least one building position which will accommodate a vessel 122 meters in length, and which have access to open water (no obstructions, such as locks or bridges and a channel depth of at least 3.7 meters). These 21 yards and an additional 18 private and eight public yards comprise the major ship repair base.

Total average shipyard employment has decreased from 131,000 in 1991 to 107,300 in 1994. Total employment for the 21 yards in the MSB has decreased from approximately 92,000 to 76,000 during the same period. Approximately 80 percent of these are production workers. Some insight into the relative labor intensiveness and productivity of U.S. yards, compared to world class shipbuilding countries, can be gained by considering the employment data for Japan. Although the United States produces less than 1 percent of the world tonnage, shipyard employment is greater than for any other country except China. In 1994, Japan produced over one-third of the world deadweight tonnage using approximately 53,000 shipyard workers compared to 76,000 employed in the U.S. MSB yards. These are only rough order of magnitude comparisons, because the ship types built are different. Military ships are more labor intensive than commercial ships, even when built in Japanese yards. The data do demonstrate the labor intensiveness of Navy ships and to some extent the difference in productivity. (Productivity will be addressed in more detail later in this chapter.)

As average shipyard employment has decreased, so have earnings relative to other countries. Average U.S. shipyard weekly earnings have increased from approximately

$510 in 1991 to $571.18 in 1994 (hourly rate change from $12.25 in 1991 to $13.82 in 1994). On average U.S. shipyard wage rates are approximately 15 percent lower than for competing industries (aircraft, transportation and heavy construction). U.S. shipyard compensation was approximately equal to that of the Japanese in 1989, but is now only about 85 percent of compensation in Japan and Denmark. German shipyard compensation surpassed that of the United States in 1986 and is now nearly 50 percent higher. In terms of fully loaded cost per employee per year, U.S. costs are approximately 20 percent less than for five European yards surveyed in 1994. [Storch, Appledore, Lamb, 1994]

With the exception of the public yards, internal training programs have been fairly minimal. Most yards have basic welder apprenticeships and some participate in regional apprentice programs in cooperation with the states or junior colleges. The trend seems to be toward more shipyard sponsored training, and two major yards have instituted cross training tied to increased pay for the attainment of added skills. This appears to be a response to required higher skill levels and the need for cross-trained individuals for group technology ship production.

3. Capital Investment

Historically, the pattern of investment in shipyards and capital improvements can be characterized as one of miscalculation in response to government incentives. Commencing in the late 1960s the Navy instituted Total Package Procurement, promising the benefits of series production. TPP required more sophisticated management and facilities, and large financial resources. This proved to be attractive to several aerospace companies and industrial conglomerates, which consequently entered the shipbuilding industry. At the same time, MARAD initiated a plan for the construction of 300 commercial ships over a 10-year period commencing in 1970. The program, called MARAD 70, was predicated on an increased demand for very large crude carriers and LNG vessels. This program was also founded on gaining the benefits of series production.

In apparent response to MARAD and Navy incentives, the industry invested an average of $200 million each year between 1970 and 1978. During this period industry profits were practically nonexistent. Kaitz [1979] estimates that between 1969 and 1976 the industry borrowed $800 million while earning profits of less than $50 million. The industry took on a long-term debt equal to 2.5 times its net worth. Between 1985 and 1993 the industry invested an average of $195 million annually. These investments include

building basins, floating drydocks, cranes, automated equipment, and facilities for fabrication of large subassemblies and pre-outfitting. [MARAD, 1995]. During 1994, $168 million was invested and $149 million is planned for 1995. Investment in these years was primarily directed toward improved efficiency and competitiveness in the Navy's construction, repair and overhaul projects because of the perceived stability of the Navy market. [MARAD, 1995] Capital investment was given further impetus in 1994 and 1995 by subsidization through the MARITECH and Title XI programs.

4. Material Markets

Approximately 40 to 70 percent of a ship, depending on type, is material or subcontracted services. Suppliers respond to the cyclicality of the product market much the same as labor. Because of the small size and sporadic demand of the ship market, many suppliers prefer to deal with other industries. The supplier base has decreased for defense industries generally and particularly for shipbuilders, and lead times have increased since the 1950s. In several instances only one supplier exists for critical parts. Examples include anchors, anchor chain and activated rudders. Quiet ball bearings used in submarines and many surface ships are available from only one source, a Japanese manufacturer. [Committee on U.S. Shipbuilding Technology, 1984] The supplier base problem is exacerbated by the practice of many foreign companies of licensing only one U.S. firm, thereby creating a sole source situation within the United States.

The cyclical product market is particularly troublesome for small suppliers. When business is slack, the shipyards often make parts themselves which would be procured outside when business is good. The small suppliers therefore see a market with even more extreme peaks and valleys than the shipbuilders.

The supplier problem is particularly acute for Naval shipbuilders because of the costs associated with government regulations, and problems associated with military specifications and standards. Requirements for "full and open competition" inhibit establishing partnering arrangements. The maintenance of reliable suppliers through such arrangements is considered essential by foreign world class shipbuilders.

Manufacturers state that military specifications do not keep pace with technology advances made by the industry. Specific problems cited are:

- Interpretation of requirements

- Outdated specifications
- Equally acceptable commercial components not qualified under military specifications
- Unreasonable software/documentation requirements
- High cost of qualifying a product not commensurate with the expected return.

The Center for Strategic and International Studies (CSIS) [Bingaman, Gansler, Kupperman, 1991] took a broader view of the integration of military and commercial technologies, including the integration of R&D, production facilities, and more purchases of commercial products by DoD (utilizing commercial standards, specifications, and buying practices). The study concluded that the tendency of the defense acquisition system to foster products and production suited only to defense results in:

- Higher unit costs for defense products than for commercially available equivalents
- Lack of access to state-of-the-art technologies that are increasingly found in the public sector
- Loss of capacity for production surge as increasing numbers of companies—particularly at the lower tiers—leave the defense industrial base
- Increasing reliance on foreign sources of supply as a consequence of the diminished industrial base
- A highly specialized work force that is undesirably subjected to the uncertainties and cyclical demands of defense procurements.

The CSIS study recommended an action agenda covering, accounting and auditing requirements, military specifications and standards, rights in technical data and software, and unique contract requirements. Most of the issues raised by this study were revisited by the shipbuilding and Navy personnel interviewed by our study team. We will address many of these in the remainder of this chapter.

B. NAVY AND DOD MANAGEMENT AND OVERSIGHT

Production is driven by the market and currently the Navy is the market for the major yards in the United States. Ship acquisition programs are administered by the Naval Sea Systems Command through program managers located at headquarters and the Supervisor of Shipbuilding, Conversion and Repair (SUPSHIPS) generally located adjacent to the major yards. The program manager is responsible overall for each ship

acquisition program. SUPSHIP is responsible for the day to day administration of each individual contract with a given yard. Additional DoD oversight is exercised through the Defense Contract Audit Agency with personnel located at contractor and sub-contractor facilities.

1. Program Management

Overall responsibility from inception to contract completion is traditionally exercised by the Program Manager (PMS). This responsibility is being expanded for the AEGIS and LPD 17 programs. The trend seems to be for the PMS to be a life cycle manager—the so-called cradle-to-grave approach to program management. Under this concept, the PMS assumes post-construction responsibility for management of modernization, overhauls, training manuals and simulators, and eventually scrapping. The PMS also contracts some management functions out to design and management consultants. This can present a problem for the shipbuilder and design firms downstream. Under Navy rules, a design firm that participates in the Navy design phase is precluded from working for the shipbuilder once the contract is awarded.

In support of the PMS, Participating Managers (PARMS) are responsible for certain equipment, such as radars, missiles, launchers, and guns. In the case of the AEGIS ships, these functions also reside within the PMS.

Although the PMS is responsible for overall program management, his/her authority is subject to standard contract clauses and political considerations. Shipyards are located in Congressional districts, and the final selection of a contractor is always the concern of competing Congressional delegations. The Congress and administration also control the production process through the budget. Efficient production depends on throughput which is affected by the numbers and timing of ship acquisition. The government reserves the right to cancel contracts at will. Cancellation clauses provide for reimbursement to the contractor for loss due to cancellation, but these clauses add to uncertainty. This uncertainty guides the shipbuilder in its production process. The effects on risk averse behavior in the use of capital and labor are further heightened by the large costs of ship programs (often measured in hundred of millions of dollars per ship).

An additional uncertainty is the government's practice of designating option ships; the shipbuilder or builders have no way of accurately predicting demand. As a result, the yards tend to substitute labor for capital and a lower technology production process

results. Option ships are often superimposed on multiple source programs, a practice which in itself limits throughput and results in higher cost production.

a. The Navy-Directed Change Clause

An issue which has long been recognized as a source of additional ship costs is the standard directed change clause written into all Navy ship construction contracts. This clause gives the government the right to change the ship at any point in the construction cycle. The government must pay the contractor for documented added material and labor (called hard-core change work) resulting from the change. But there is no accepted way of documenting additional costs due to disruption of the contractor's production process for the individual ship or for the yard as a whole. NAVSEA and SUPSHIP personnel accept the fact that changes are expensive, although they do not necessarily accept the cost of associated delay and disruption as legitimate. In the past, the Navy often appeared to adopt the position that many delay and disruption claims provide a way for the shipbuilder to get well financially after under bidding a contract. Hammon and Graham [1980] showed that, for the Spruance class ships, disruption accounted for approximately one labor hour for each hard-core change hour, but the Navy has never officially accepted disruption costs.

The current Navy position on changes is that some changes are unavoidable. Mistakes in design drawings and new technology are the most common reasons given. Design mistakes must generally be corrected when discovered. Changes to incorporate new technology or changes in mission may be delayed until after delivery. The choice between implementing a change in the yard or backfitting is based on cost effectiveness analysis done at SUPSHIP and/or NAVSEA. In the case of the DDG 51, the Navy has chosen to consolidate major changes and implement them as block upgrades in subsequent production flights.

b. Government Furnished Equipment

Use of Government Furnished Equipment (GFE) arises for two primary reasons. First, because the Navy assumes design responsibility through the contract design phase, long lead time items must be ordered before the shipbuilding contract is let. The Navy therefore orders these items and provides them to the eventual shipbuilder as GFE. The second, and perhaps more important reason for GFE arises from the nature and cost of the combat systems used on modern combatants. Advanced combat systems now account for

more than half of the cost of a combatant ship. These systems are usually developed by the Navy and industry under contract to the Navy on a different time schedule than the ships on which they will be installed. In some cases, the systems cut across more than one ship contract. The Navy retains responsibility for these systems, and provides the equipment to the shipbuilder as GFE. GFE was used even under the Total Package Procurement concept. Late delivery of GFE items has been cited as a basis for Requests for Equitable Adjustment (REA) against the LHA and Spruance class ships as well as nearly every class built before or since. These claims are generally difficult to substantiate or to refute because of overlapping causes for delay. In the case of the Spruance, Navy studies concluded that delay caused by GFE represented only 8 percent of the total 350 months of ship delay and overlapped delay caused by late contractor furnished equipment (CFE). The study results were inconclusive and late GFE continued to present an avenue for REAs on those and later ship contracts.

Because use of GFE shifts responsibility for part of Material Control away from the shipbuilder to the government, it conflicts with material control and Just-in-Time delivery of interim products which are at the heart of production control. It is frequently argued that Navy personnel should play a key role in integrating the combat system aboard ship given the familiarity gained during system development. However, during our interviews with Navy and yard personnel the consensus was that the yards carry out integration. The Navy only orders the material and has it delivered to the yard. The yard must then take responsibility for storage, security and corrosion control.

The GFE issue turns on incentives. The shipyard production process is based on one material control system which is coordinated with and responds to the yard's production process. The yard's incentive is to conserve storage space and maintenance costs associated with stored material, and to maintain an efficient flow of material. The incentive of Navy personnel is to ensure that the material is never late, regardless of the cost in interest, storage, security and corrosion control that might result.

c. Innovations in Program Management

The LPD 17 program manager has been given authority to organize his staff and many of his functions as he sees fit to improve the system. Because the program is on-going, it is not yet clear what changes will eventually be made to the overall acquisition system. In addition to reforms associated with basic concepts of systems oriented design

and construction, the PMS is reorienting its own management system. This includes basic tools of management, such as the use of computers, personnel and resources generally. One proposal, for example, is to move the PMS (or some element thereof) to the construction site. Another proposal is to eliminate those CDRLs which do not contribute to the direct management of the ship construction, and rely on the shipbuilder's internal management system. In place of Quarterly Progress Reports and meetings, the Navy would be given access to applicable yard management data files. The extent to which the PMS would have undocumented access to the shipbuilder's proprietary information is an issue that must be worked out with the contractors. (Such access became a major issue during the TPP contracts for the DD 963 and LHA but was never adequately resolved.)

As the first major ship acquisition since the OSD acquisition reform initiative, the LPD 17 PMS is also the test bed for many acquisition reforms. One area of acquisition reform which is being addressed by the Navy is the use of commercial standards. The LPD 17 is to be built using commercial specifications and standards to the maximum extent possible. To further this objective, the Program Manager is requiring that use of Military Specifications be justified in detail. (The elimination of MilSpecs unless they are justified is now DoD policy.) The usual procedure is the other way around, with the onus on justifying commercial specifications. Contract design had begun before the publication of Secretary Perry's acquisition reform memorandum. Even so, as of early 1995, the number of references to military specifications and standards in the LPD 17 design specification had been reduced from over 1450 to 334. [Tibbitts, and Keane, 1995]

2. Supervisor of Shipbuilding, Conversion and Repair (SUPSHIPS)

As the Administrative Contracting Officer, SUPSHIP is responsible to NAVSEA for on-site contract administration. SUPSHIP's primary responsibility is to ascertain physical progress in support of periodic progress payments. In addition SUPSHIP also monitors the contractors quality assurance program, verifies labor and material charges, and change order pricing.

a. Navy Directed Changes

SUPSHIP also authorizes Level IV engineering change proposals (ECPs), i.e., those which are not reserved for approval by the PMS, NAVSEA, or CNO. In general these are changes originated by the contractor, SUPSHIP, or a Trial Board that do not

affect performance and have a cost of $25,000 or less per ship or $375,000 per contract. The PMS may authorize a per-ship threshold above $25,000 for particular types of changes. A common complaint of SUPSHIP personnel that we interviewed was that the dollar threshold for SUPSHIP action is too low, and changes which have to be resolved at the headquarters level result in excessive decision delay. Change Control Board actions take 200 to 400 days according to one PMS, who believes that 17 days is adequate. One SUPSHIP stated that the average processing time for change authorizations received between October 1994 and March 1995 was 356 days. Most of the Navy and shipyard personnel that we interviewed agreed that many of the problems associated with changes stem from the following factors:

- Adversarial relationship between contractor and Navy
- Risk avoidance rather than risk management
- Lack of trust between contractor and Navy personnel
- Changes adjudicated at too high a level resulting in extended delay
- Sequential identification and review of desired changes
- Underbidding by contractor.

SUPSHIP Bath and Bath Iron Works emphasized the point made in the first bullet. They stated that there have been no Requests for Equitable Adjustment (REAs) in the past three years, and attributed it to a major effort by both parties to reverse what had been an adversarial relationship. SUPSHIP New Orleans has proposed a change processing improvement proposal which incorporates:

- During production implement only changes essential for the performance of primary mission.
- Estimate up-front volume/timing of changes during contract performance.
- One common Change Control Board (Contractor, PMS and SUPSHIP).
- Eliminate number of change levels.
- Incorporate process improvements into contracts at award (if appropriate).

The proposal also includes joint scoping and parallel review, pre-pricing disruption, commitment of SUPSHIP and yard to reducing adversarial relationship, and streamlining the change order process.

b. Quality Testing

SUPSHIP also monitors the contractor's Quality Assurance system. Navy contracts require the contractor to have in place an approved Quality Assurance system which can be monitored by the SUPSHIP inspectors. However, both contractors and SUPSHIP personnel that we interviewed reported that inspection includes a great deal of actual quality testing. We were unable to get an estimate of the actual time spent on quality testing, only that it was considerable.

We do not argue that SUPSHIP is unnecessary given the Navy's method of operation, but rather that the size of the organization—approximately 400 personnel at each major shipyard—might be reduced by careful examination of the functions it performs. Progressing for the purpose of payments to the contractor, monitoring the yard's QA system, and change order decisions and pricing are necessary functions under the present system. At issue is whether the Navy takes too much responsibility which could be safely left to the contractor, and whether the Navy's objectives could be accomplished by instituting a different set of incentives for the shipbuilder. Commercial operators, who of course are dealing with a simpler product for the most part, generally have one or two persons on site in addition to a Coast Guard inspector and an American Bureau of Shipping (ABS) representative. Commercial operators generally make progress payments at major milestones, such as keel laying, or trials. Owner furnished equipment is essentially non-existent, and perhaps most importantly, the builder knows that if he doesn't perform satisfactorily there will be no further contracts from that owner.

c. Systems-Oriented Work Breakdown Structure (SWBS)

The Systems-Oriented Work Breakdown Structure (SWBS) used by the Navy has long been an issue with shipbuilders and with some SUPSHIP personnel. The SWBS is a classification system used to collect costs by hierarchical system, such as Hull Structure, Propulsion Plant, or Electric Plant. The SWBS is used from design to scrapping for such tasks as cost estimating, progressing, and maintenance. SWBS is perhaps most useful during conceptual and preliminary design and for Rough Order of Magnitude (ROM) studies where the ship can be viewed as a collection of systems. Problems arise when the SWBS is used to keep track of production, particularly for progress payments. Ships are built according to a Product-oriented Work Breakdown Structure. Consequently, the contractor and SUPSHIP must translate between their PWBS and the Navy's SWBS for

purposes of progress payments and reports. This is both expensive and, according to both ship yard and SUPSHIP personnel whom we interviewed, unnecessary. Additionally, one shipyard executive stated that the translations are often inaccurate. One yard, which appears to be fairly advanced in many respects, uses the SWBS to define work packages in order to avoid such a translation. There is perhaps nothing more inhibiting to efficient product-oriented group-technology ship production.

The relationship between SWBS and product oriented work breakdown is further complicated in that ship operators naturally revert to a systems perspective after the ship has been delivered. Thus, even if a PWBS were adopted for construction, a SWBS would still be needed later on. The Carderock Division of the Naval Surface Warfare Center is developing a PWBS/SWBS translation scheme in conjunction with the product-oriented cost model.

3. OSD Oversight

Oversight is exercised by inspectors and auditors—primarily by the Defense Contract Audit Agency (DCAA)—in accordance with Cost Accounting Standards (CAS) tailored to unique government requirements. These standards and unique cost accounting principles and the organizations which administer them evolved to ensure that the government pays reasonable prices for the goods it purchases, particularly in an environment where contractors were operating in a cost plus fixed fee environment. According to Bingaman, Gansler, and Kupperman [1991], "...some of these standards differ appreciably from generally accepted accounting practices in the commercial sector." The CAS differs from Internal Revenue Service (IRS) requirements, for instance, in the way depreciation is calculated. A major criticism is that cost accounting standards interfere with sound business practice in that internal information must be geared more toward meeting regulatory requirements than management needs.

One area which appears to be the most troublesome is in requirements for cost or pricing data. Although these are intended to protect the government, the CSIS study as well as shipbuilders that we interviewed claim that auditors often require cost and pricing data as well as full competition among sub-contractors even when the contract is fixed price. Additionally, the requirement to be able to track costs, even for commercial equipment, flows down from the prime contractor to its suppliers because the prime must protect itself in the case of an audit.

One result of the current government dictated accounting rules is that the government is often unable to obtain state-of-the-art material. In many instances "commercial manufacturers, who develop products in 3-4 years as opposed to 7-8 years for government development of similar items, do not find it practical to change their accounting and management practices for what may be small and sporadic sales." [Bingaman, Gansler, and Kupperman, 1991] Estimates of the additional costs associated with doing business with the government are fairly consistent. The Carnegie Commission on Science, Technology and Government [1992] estimated that overhead, or management and control costs, associated with DoD acquisition were approximately 40 percent of the acquisition budget compared to 5 percent to 15 percent for commercial buyers. "This figure includes both the government's internal costs, and the costs borne by DoD contractors and ultimately reimbursed by the government." [Perry, 1995] Other studies estimate that the government pays a premium of about 30 percent of the cost to commercial firms because of unique accounting and competition requirements. [Bingaman, Gansler, and Kupperman, 1991]

4. Summary of Government Management Issues

Program management of the LPD 17 promises to bring changes to Navy overall ship acquisition management. PMS 17 is integrating a number of initiatives—including PODAC, affordability through commonality (ATC), the use of commercial standards/specifications, and GFE practices. The current LPD 17 acquisition plan calls for the winning contractor to acquire the weapons systems directly from the manufacturer. The government will specify the systems to be acquired but will not buy them as it now does. This Government Specified Equipment (GSE) approach appears to offer a reasonably efficient means to provide the shipbuilder with material developed by the government.

The yards who are aggressively seeking commercial work, such as Newport News, may very well put pressure for change on the system. Newport New's Double Eagle program manager has stated that management practices that do not add value will not be allowed into his area of the yard. This will introduce to shipyards a dual management system much like that employed by aircraft manufacturers. The need for integrating commercial and military production under one agile management system is at the heart of acquisition reform.

On-site contract administration is driven by the needs of the Navy management system. A major function of SUPSHIP is to determine progress payments. Changing to the system used by commercial companies would require the shipbuilder to assume much more of the financing. Given the very long construction times required for complex combatants, this would greatly increase the financial risk borne by the shipbuilder. To the extent that the government pays a lower interest rate, this would also increase the cost of the ship. However, considering these as added costs begs the real issue. The current system of progress payments based on work in process is a major deterrent to efficient production, because there is little incentive to reduce the time of construction or the amount of unneeded material on hand. Just-in-time material procurement and delivery to the work site is based on efficient scheduling of labor and reduction of capital tied up in raw materials and interim products. The lack of just-in-time material control in yards supplying Navy ships is, therefore, an expected result.

Decision delay, resulting from the requirement for headquarters approval of changes above a certain threshold, could be reduced by raising the threshold. The issue of hands on quality inspections is perhaps one area where administration costs could be reduced with little change in Navy stated policy. Theoretically, Navy inspectors are charged with insuring that the shipbuilder complies with his own quality assurance system. This policy could be extended to the shipbuilder's management system and the concurrent elimination of many CDRLs. Hands on testing and much of the current audit requirements should be required only when discrepancies are found in the contractor's system.

According to interviewed personnel, SUPSHIP management costs are on the order of 3 percent of the total contract. However, this does not include the cost of yard personnel required to interact with the SUPSHIP personnel and non-value added administrative practices.

The problems with accounting and pricing rules are treated in detail by Secretary Perry in his acquisition reform initiative and are beyond the scope of this study. It is clear though, that this is an area that must be addressed effectively if the Navy is to continue acquiring first rate ships and if the industrial base is to be preserved. One of the objectives of acquisition reform is to facilitate the use of a single management and accounting system for all customers, by firms who sell to the government. This has been accomplished by the major shipyards, since for practical purposes their only customer is the government. However, the single system costs the government a very high premium. The consensus

estimate that the government pays a premium of approximately 30 percent [Perry, 1995] because of restrictive business practices represents a significant cost. A greater cost, perhaps, may be the inability to acquire the most up to date equipment, and the effect that these regulations have on the production process. Furthermore, it is not clear that a viable Navy ship industrial base can be preserved without the entry of U.S. shipbuilders into the world market. The major U.S. yards have adapted their management, marketing and production processes to the Navy market, but at a high cost in national resources. As stated by Tibbitts, Keane, Covitch and Comstock [1993],

> "By avoiding the adoption of modern design and production processes, both the Navy and the shipbuilders will continue to become ever more locked into a 'single customer-single supplier' death spiral. Maintaining the industrial base means having an industry that can compete commercially as well as militarily."

C. U.S. SHIPBUILDING PRODUCTIVITY

The consensus of many studies of ship productivity is that world class shipbuilders produce comparable ships in about half the time and with approximately half the labor hours required by U.S. shipyards. The previous two sections considered the effects of markets and government management on productivity and ship costs. This section will address productivity from the viewpoint of shipbuilding process and technology.

1. Comparative Shipbuilding Productivity

It is impossible to estimate relative productivity of the major U.S. and foreign shipyards directly. Over the past two decades, U.S. yards have concentrated on military vessels to the exclusion of commercial ships. Even Jones Act ship construction has been minimal over the past 15 years, and unsubsidized commercial construction has been non-existent.

a. Commercial Ship Productivity

Most comparative productivity studies have been based on surveys and the expert opinion of people familiar with shipbuilding in U.S. and foreign yards. One such study, by the Center for Naval Analyses using 1990 data, estimated relative single ship and series construction costs for a 54,000 dwt product tanker and a 70,000 dwt dry bulk carrier.

[Rost and Tighe, 1992] Table 22 shows the CNA cost comparison for the eighth ship assuming series production.

Table 22. Comparative Costs for 54,000 dwt Product Tanker and 70,000 dwt Bulker (Eighth Ship in Millions of 1990 U.S. Dollars)

	Japan		Korea		German		U.S.	
	54k PT	70k B	54k PT	70k B	54k PT	70k B	54k PT	70k B
Labor	6	4	6	4	14	9	12	8
Material	28	21	26	19	26	19	29	21
Overhead	13	10	14	9	16	11	13	9
Total	47	35	46	32	56	39	54	38

Source: [Rost and Tighe, 1992].

The table was constructed using a U.S. learning rate of 88 percent for labor and 95 percent for material. The differential between U.S. and Japanese costs is only 15 percent and 9 percent for the Product Tanker and Bulker, respectively. This appears low based on the literature. Note that overhead and the cost of materials is nearly equal between U.S. and Japanese yards. Subcontracting, which is greater for Japanese yards, is included in material which should result in higher costs for the Japanese. However, Japanese yards have a much better developed and responsive supplier base than U.S. shipbuilders. Although material is available to all countries at near world competitive prices, the Japanese could be expected to buy at advantageous prices because of vertical integration and builder-supplier agreements.

The primary difference in total cost is in labor productivity. Table 23 compares labor productivity, defined as man-days per ship, for the 54,000 dwt product tanker. Both series and single ship productivity are shown for Germany and the United States. Japan and Korea only build using series production. Comparative hourly labor compensation in 1990 is also shown. Note that compensation in 1990 was approximately equal for the U.S. and Japan. Korean shipyard compensation has increased and German compensation has decreased relative to the U.S. since 1990. Japanese compensation has increased relative to the U.S. and is now approximately 15 percent greater.

Table 23. Comparison of Labor Hours and Hourly Compensation for a Standard 54,000 dwt Product Tanker

Productivity Measure	Series Production				Single Ship	
	Japan	Korea	Germany	U.S.	Germany	U.S.
Productivity (Employee-Days/Ship)	45,000	99,000	65,000	100,000	95,000	146,000
Hourly Compensation (In 1990 U.S. Dollars)	16.00	7.80	26.50	15.60		

Source: [Rost and Tighe, 1992].

As noted by the authors, Japanese yards would be expected to improve with time and this is borne out by recent studies of relative productivity. Although U.S. yards have invested in productivity enhancements since 1990, they have not built commercial ships.

An earlier study [Bunch, 1989] compared the construction time and manpower requirements for the construction of a general mobilization ship in a Japanese shipyard and in a U.S. yard. The specific shipyards were Kawasaki Heavy Industries (KHI) located in Kobe, Japan and Avondale Shipbuilding Industries (ASI) in New Orleans. The study team asked current and former employees of the two yards to analyze the ship and the shipyards in order to arrive at detailed productivity comparisons. As a result, the data were more fine grained than those available to the CNA study. The study's findings are expressed in terms of labor-hours and schedule rather than dollar costs. All schedule and labor-hour estimates are based on the first and fifth ship in a series using 1980 and 1983 data for KHI and ASI respectively. Table 24 compares labor-hour requirements for Hull and Outfitting activities for the first and fifth ships for the two yards. The Japanese yard would use approximately 40 percent of the labor-hours required by ASI. This agrees fairly closely with the 50 percent figure in the CNA study.

The study analyzed differences in the two yards and reasons for the greater number of required labor-hours for the U.S. yard. Significant findings included:

- Organization for production:
    - ASI—Functional. The two main departments are Production and Support, which includes Production engineering and Planning, Accuracy Control and Material Control, Warehousing, Trials and Testing, and Main Machinery and Propulsion Installation.
    - KHI—Product orientation. The two main departments are Hull and Outfitting, each with their own support personnel.

Table 24. Labor-Hour Comparisons for Constructing the PD214 General Mobilization Ship in the KHI Kobe and ASI Shipyards (Thousands of Labor-Hours)

	First Ship		Ratio	Fifth Ship		Ratio
Production Activity	**ASI**	**KHI**	**KHI/ASI**	**ASI**	**KHI**	**KHI/ASI**
Hull Activities						
Cut & Fab	107	34	0.32	99	31	0.31
Sub Assy & Assy	135	95	0.70	126	86	.68
Erection	219	96	0.44	204	87	.43
Prod. Eng.	48	13	0.27	4	0	0.0
Mold Loft	54	32	0.59	50	1	0.02
Cranes	56	16	0.29	53	15	0.28
Misc.	44	2	0.05	41	20	.05
Subtotal	663	288	0.43	577	222	0.38
Design Eng.	148	23	0.16*	13	0	0.0
Total Hull Activities	811	311	0.38	590	223	0.38
Outfitting Activities						
Pipe Fab & Assy	125	116	0.93	106	106	1.00
Mach Fab & Assy	49	35	0.71	47	32	0.68
Elec Fab & Assy	60	31	0.52	56	30	0.54
Sheet Met F & A	64	23	0.36	60	21	0.35
Insulation	29	24	0.83	27	22	0.81
Painting	107	44	0.41	100	40	0.40
Fitting & Outfit	143	56	0.39	134	51	0.38
Testing	32	2	0.06	28	2	0.07
Cranes	14	1	0.07	13	1	0.08
Serv & Unalloc.	50	13	0.26	47	12	0.26
Prod. Eng.	86	26	0.30	8	1	0.13
Subtotal	758	371	0.50	622	315	0.51
Design Eng.	265	28	0.11*	23	0	0.0
Total Outfitting Activities	1023	399	0.39	645	315	0.49
Total Labor-hours	1834	710	0.39	1235	537	0.43

Source: [Bunch 1987].

* Second ship learning when first ship Engineering is included is 71 percent for ASI and 85 percent for KHI. The assumed learning for the remainder of the series is the same for both yards.

- The area of the ASI shipyard is over twice as great as the KHI facility—1.294 million square feet compared with 0.521 million for KHI. The size difference, combined with the layout of the two yards, is such that ASI travel distances are 6 to 15 times greater for comparable blocks. The greatest ASI travel distance—7040 feet—is for high volume flat blocks compared to 420-1120 feet for KHI.
- Outfitting:
  - KHI—Outfitting of pipe and painting is initiated 2 1/2 months before keel laying. Almost all of the engine room units are built up in the engine shop. Outfitting is completed one month before delivery. Outfitting on-board was reduced from 57 percent in 1980 to 40 percent in 1985.
  - ASI—Outfitting policy is essentially the same as for KHI. Implementation seems to be different though. Material lead times are greater at ASI, and KHI does more on-unit and on-block outfitting. At ASI 73 percent of units (blocks) are outfitted prior to erection, yet the time between launch and delivery is 6 1/2 months compared to 4 months for KHI.
- Subcontracting:
  - KHI subcontracts much more of production work—60 percent of paint and 30 percent of pipe outfitting, scaffolding, and insulation. ASI subcontracts less than 5 percent of direct labor. Traditionally Japanese yards have many sub-contractors, some wholly owned, right outside the gate who are little different than yard employees. However, for accounting purposes this work is counted as material rather than production labor.

Contract to delivery times were also greater for ASI than for KHI. Contract to delivery was 140 weeks for ASI compared with 60 weeks for KHI. An important reason for the longer time is the longer material lead time for ASI. Table 25 compares the time from ordering to delivery for major material items.

If ASI order lead times for these items were reduced to that of KHI, the time from contract to delivery could be reduced from 140 to 118 weeks with no change in production practice. This would still be nearly twice as long as for KHI--60 weeks for contract to delivery for first ship.

Table 25. Comparison of Material Delivery Time for the PD214 General Mobilization Ship in the KHI Kobe and ASI Shipyards (Time Between Order and Delivery in Weeks)

Type Material	ASI	KHI
Hull Steel	35	9
Main Valves	55	17
Steel Pipes	46	13
Aux. Machinery	52	39
Boiler	62	35
Main Condenser	65	37
Main Reduc. Geat	61	41
Main Turbine	61	41

In addition to longer material lead times, the ASI Engineering Drawing and Material List schedules take about twice as long as KHI. However, engineering drawings are not on the critical path at ASI because Contract to Keel is twice as long because of the long lead time for critical items (e.g., power plant). Boiler lead time--14 months for ASI and 8 months for KHI--determines keel laying for both yards. The yards are very similar in the way that Engineering and Material Control deal with outfit items except for sub-contracting and material delivery times.

b. Naval Ship Productivity

The United States is the world leader in naval ship construction and design. Although procurement processes of most major navies tend to be similar to those of the United States, there are some significant differences, particularly in productivity, that bear consideration. A few comparative studies of U.S. and foreign naval ship design practices are available, but these do not address production in any real detail.

Ferreiro and Stonehouse [1991] in conjunction with NAVSEA and the United Kingdom Sea Systems Controllerate (SSC) conducted an analysis of the reasons for differences in size and cost of U.S. and UK ships designed for similar missions. They examined conceptual U.S. and UK ship designs based on identical mission requirements. The study concentrated on ship design, but a comparison was made of relative construction costs of the UK baseline ship built in a U.S. and a UK shipyard. They estimated that the U.S. yard would require fewer labor hours than a UK yard, but because

of higher U.S. yard material and labor prices the ship would cost 8 percent more to build in a U.S. yard.

The Japanese Kongo (DDG 173) and U.S. DDG 51 Aegis ships provide some basis for comparison of production costs of similar Naval ships built in U.S. and Japanese shipyards. Available data come from trip reports by OSD and NAVSEA personnel. [Martin, McGough, and Rains, 1990], [Summers, 1993]

The first three ships of the Kongo class were built at the Mitsubishi Heavy Industries (MHI) Nagasaki yard. The remaining ships of the class are being built at the IHI Tokyo yard. There are important differences in the two ship classes which make a direct comparison of required labor-hours impossible. However, the magnitudes of the labor-hour differences allow us to draw meaningful conclusions about relative productivity.

Design of the Kongo was accomplished at MHI. Although MHI uses CAD for all of their commercial projects, only about 50 percent of the Kongo design was CAD. Design, including preliminary (6 months), contract (6 months) and detail took about 4 years, and was accomplished by a design staff of 140 at the yard plus 60 designers from MHI's Marine MARITECH located off-site. Because ship contracts are allocated rather than bid competitively, detail design can begin before budget approval. The Kongo detail design was started 21 months before contract signing. Some of the design personnel (electrical) also do production work. The electrical designers weld hangars and pull cable.

Table 26 compares design labor-hours for similar ships. Note that the CG 47 used the same hull form and main machinery as the DD 963, with major changes in systems and the superstructure. The DDG 51 was severely constrained in volume and geometry by the Secretary of the Navy, resulting in many interferences and restricted room for outfitting. Many of the interferences were corrected after the fact by transferring the design to CAD. Japanese ship design is facilitated by the use of concurrent engineering for both commercial and military ships. In the case of the Kongo, some design savings were also realized through extensive study of the DDG 51, particularly of the weapons system. Even so, the Kongo design man-hours are remarkably low.

Table 26. Comparison of Design Labor-Hours for Similar Type Ships

Ship	Design Labor-Hours
JDS Kongo	1,200,000
DDG 51	6,000,000
DD 963	5,000,000
CG 47	3,000,000

Source: [Martin, McGough, Rains, 1990].

Table 27 compares the first ship cost estimates for the DDG 51 and JDF 173 as of 1990 in U.S. dollars.

Table 27. Estimated First Ship Cost Comparisons for the DDG 51 and JDS Kongo ($U.S.)

Item	DDG 51	JDS Kongo
Combat System	400,000,000	400,000,000
Design,	200,000,000	100,000,000
Construction	400,000,000	300,000,000
Management	100,000,000	100,000,000
Total	1,100,000,000	900,000,000

Source: [Martin, McGough, Rains, 1990].

In 1990 the first ship had not been completed and the production data were estimates. Martin, McGough and Rains [1990] attributed the cost differences primarily to design efficiencies with production efficiencies playing a lessor role.[2] A comparison of man-hours for selected ships indicates that the Japanese also experience savings in production labor for Naval ships. Table 28 compares production labor-hours for the fourth ship for selected Naval ships. Although the DDG 176 is the fourth ship of the Kongo class, it is the first ship of the class built by IHI.

2 A direct comparison of production would seem to be obviated by significant differences in shock and cable laying standards. However, Summers did not develop an estimate of the work content of these differences.

Table 28. Production Labor-Hours for the Fourth Ship in a Series for Selected Naval Ships

Ship Class	Full Load Displacement (tons)[c]	Keel to Commission	Production Labor-Hours
DD 963	8040	38 mos.	3,800,000[a]
FFG 7	3585	30 mos.	2,500,000[a]
CG 47	9466	33 mos.	5,000,000[a]
Kongo (DDG 176)	9485	34 mos.	2,200,000[b]
DDG 51	9033	24 mos.	4,000,000[a]

[a] [Rains, 1994].
[b] [Summers, 1993].
[c] [Janes Fighting Ships, 1995].

As with relative commercial ship productivity discussed earlier, direct comparisons of labor-hours is not possible because of the number of labor-hours that are sub-contracted by the Japanese. Summers states that 70 percent of pipe is fabricated outside the yard by small vendors. If we assume that 30 percent of insulation and 60 percent of painting is also sub-contracted as Bunch [1987] found for commercial ships, and that these activities represent the same proportion of total hours as for the PD214, then subcontracted labor would be approximately 20 percent of total labor. This should be an upper limit since we are applying the 70 percent to pipe fabrication and assembly. This would mean that the adjusted production labor-hours would be no more than 2,750,000 for the DDG 176. This is only 250,000 more than for the FFG 7, and approximately 70 percent of the DDG 51 labor-hours for the fourth ship.

A sample of significant differences in Japanese design and production practices which impact producibility or ship cost generally are listed below. See [Summers, 1993] for a detailed list of production practices for the Kongo.

- The Kongo is 2 feet wider and 24 feet overall longer than the DDG 51. Displacement is 9485 full load tons compared to 8500 for the DDG 51. The additional volume of the Kongo results in better producibility and fewer interferences than was initially experienced in the DDG 51. This is further enhanced by cable ways which are straight for longer distances than for the DDG 51. The Japanese also stack cables during initial construction. The U.S. Navy allows cables to be only one deep.
- Little consideration is given to shock or an explosion inside the Kongo, and nuclear decontamination facilities are not as extensive as for the DDG 51. Distributive systems are closer than the 2'' required by the U.S. Navy.

- Government changes are almost nil. There were a few electrical specification changes between the first and second hull, but none between the second and third hulls. Employees are invited to submit recommendations for improving the design or producibility. One thousand such recommended changes were submitted by the time of launch. All were acted on; either accepted or the reasons given the employee for non-acceptance.
- The number of personnel at the Nagasaki CPO—the Japanese version of SUPSHIPS—is eight.
- Cross-trained teams are responsible for each block or zone. All requirements are contained in a book of drawings and notes for each zone. Only five union skill groups cover the whole yard. There are no cleaners and each team cleans up after itself. There is very little storage of materials on board. Material and services are removed when not needed. The ship and work areas are very clean and easy to get around in.
- The main engines are installed later than in the United States. Most of the equipment load out and installation work is completed before engine load out and deck house installation.
- Hull joining is very neat and cherry pickers are used in place of staging. All welding is done from the inside using a ceramic tape backer. All blocks are protected with paint and no rust is evident. The blocks do not go through blast and paint between outfit and erection welding. Deck straightening is done in the outfit stage with almost none done in the erection area.
- Pipe flanges are used extensively and almost no pipe welding is done aboard ship.

Perhaps the most significant difference is in organization for production. As for commercial shipbuilding, Japanese naval production organizations are production oriented rather than being organized functionally. Each of two main departments—Hull and Outfitting—has its own support personnel. This is particularly important with regard to production engineering and accuracy control. The U.S. yards that we visited were particularly weak in these areas. One yard is making a special effort to implement statistical control procedures. However, they are still organized along functional lines with a separate accuracy control division. The Japanese treat accuracy control as everyone's job down to the zone work groups and individual mechanics.

2. Technology Comparisons of U.S. and Foreign Shipyards

A survey, sponsored by the NSRP, of the technology level of five foreign--four European and one Japanese--and five U.S. shipyards was conducted in 1994 by Storch, Appledore International Ltd., and Lamb [1994]. The research had the following five objectives:

- Determine the relative technology levels in use in shipyards in the United States and in leading shipyards overseas.
- Determine the relative status of shipbuilding/ ship repair facilities in the United States and in leading shipyards overseas.
- Determine the facilities required by U.S. shipyards to compete against leading overseas shipyards and evaluate the relative cost effectiveness of any required facility improvements.
- Provide an indication of the competitive position of U.S. shipyards in relation to the leading overseas shipyards in terms of cost and time, and determine how overseas shipyards are currently able to produce ships in a shorter time and for less cost than U.S. shipyards.
- Identify the major factors to be addressed and actions taken in order to allow U.S. shipyards to enter the international shipbuilding or ship-repair markets on a competitive basis, relating to technology levels, operational practices (both internal and external to the shipyard), and facilities.

a. Technology Assessment

Sixty-nine elements were addressed, grouped according to seven major shipyard activities. The elements include not only hardware and facilities, but the procedures used to operate them, planning and controlling the work, and production engineering. Each element and activity was weighted according to its relative importance in the shipbuilding process. Weighted averages were then calculated and the two groups (U.S. and foreign) were ranked according to their level of technology for each activity and element. Rankings were from one to five based on where the yards fell relative to best practice for given time periods between 1960 and 1990. The five levels are as follows:

- Level 1: Shipyard practice of 1960
- Level 2: The technology of shipyards modernized in the late 1960s or early 1970s.
- Level 3: Good shipyard practice of the late 1970s.

- Level 4: Shipyards that continued to advance their technology during the 1980s. Level 4 technology is characterized by a single dock, with good environmental protection, fully developed operating systems and extensive early outfitting.
- Level 5: State of the art shipbuilding technology in 1990. Level 5 implies the additional use of automation, where it can be used effectively, and by integration of the operating systems (e.g., the effective use of CAD). It is characterized by efficient computer-aided material control, and by effective quality assurance.

Table 29 shows the overall technology of the nine yards--only the four major U.S. yards surveyed are included. All but two of the foreign yards have a higher overall technology level than all of the surveyed U.S. yards.

Table 29. Comparison of Overall Technology Levels

Yards	U.S.	Foreign Yards
1	3.2	3.0
2	3.4	3.3
3	3.4	4.1
4	3.5	4.4
5		4.5

Source: [Storch, A&P Appledore, & Lamb, 1994].

Table 30 compares the survey results at the activity level. The table uses data from the four major U.S. yards visited and five foreign yards. The foreign yards were:

- AESA Sestao, Spain
- Harland and Wolff, UK
- IHI Kure, Japan
- Kvaerna Govan, UK
- Odense, Denmark.

The results for individual elements are shown in Appendix B. A similar survey was done in 1978 by Appledore and the results of that survey are also included in Table 30. With the exception of Activity (F) the 1978 survey included all of the activities covered in the 1994 survey. An activity labeled "Amenities" was included in the 1978 survey but was excluded in the 1994 survey and hence is omitted from the table. The earlier survey

ranked the activities on a scale from 1 to 4, so the current levels would be expected to be greater by 1 (5.0-4.0) to 1.25 (5.0/4.0). Table 30 therefore indicates both relative rankings between foreign and U.S. yards, and whether the surveyed yards on average kept pace with state of the art technology improvements during the 1980s.

Table 30. Comparison of 1978 and 1994 Survey Results

	1978 Survey			1994 Survey		
Group	U.S. Shipyards	Foreign Shipyards	Delta	U.S. Shipyards	Foreign Shipyards	Delta
A. Steelwork Production	2.25	2.91	0.66	2.91	3.46	0.55
B. Outfit Production and Stores	2.36	2.43	0.07	3.30	3.75	0.45
C. Other Pre-erection	2.06	2.76	0.70	3.83	4.06	0.23
D. Ship Construction	2.48	2.86	0.38	3.18	3.98	0.80
E. Layout and Environment	2.33	2.89	0.56	2.94	3.31	0.37
G. Design/ Drafting/Prod Eng./Lofting	2.92	3.17	0.25	3.45	4.33	0.88
H Organization and Operating Systems	2.98	3.03	0.05	4.04	4.67	0.63
Overall Technology	2.50	2.90	0.40	3.40	4.00	0.60

Source: [Storch, A&P Appledore, & Lamb, 1994].

The U.S. yard average technology level is lower in all seven activities and the overall difference has increased by 0.20 since the 1978 survey. Since 1978, both groups have progressed about as expected (0.9 for the U.S. and 1.1 for the foreign yards), but the gap has widened somewhat. The U.S. yards have made gains on their foreign competitors in three areas, (A.) Steelwork Production, (C.) Other Pre-erection, and (E.) Layout and Environment. In Steelwork Production, the U.S. yards are only at the 1978 level of the foreign yards. The most progress has been made by the U.S. yards in Other Pre-erection Activities, 1.77. This is particularly significant because it indicates that more work is being done in the workshops rather than in the erection area. The least progress by both groups was made in Layout and Environment, indicating that the yards are constrained by their physical layout.

The U.S. yards have fallen the furthest behind in Activity (G.) Design/Drafting/Production Engineering/Lofting, from a fairly close position in 1978. In three elements, Steelwork Coding Systems, Parts Listing, and Dimensional and Quality

Control, the U.S. yards have lost leads held in 1978. In the last of these elements the 1994 level was lower by 0.2 than in 1978 (3.0 vs. 3.2). The second greatest gain by the foreign yards was in Activity (H.) Organization and Operating Systems. Although the U.S. yards improved by the expected amount, 1.06, the foreign yards improved by 1.64. The foreign yards improved the expected amount, 1.12 in Activity (D.) Ship Construction, while the U.S. yards improved by only 0.70, falling behind by an additional 0.42. In painting, the U.S. yards have essentially stood still, with an increase in technology level of 0.1. Both groups have made about the expected progress in Activity (B.) Outfit Production and Stores, 0.94 for the U.S. and 1.32 for the foreign yards.

Major differences in current technology levels are in:

- Activity (D.) Ship Construction and Outfit Installation. The U.S. yards had a lower level in all elements and the following elements were lower by at least 0.9.
    - Erection and fairing. U.S. yards do not control for welding distortion and leave excess stock on the blocks.
    - Onboard services. Foreign yards pre-plan services in modules so they can be removed when not needed. Fewer services are required because more work is done on unit and on block.
    - Staging and access. This is a particularly troubling element. Foreign yards use only cherry pickers rather than staging, which is time consuming. They also do more work at the unit and block stage, eliminating the need for staging.
    - Engine room machinery and Hull engineering. More pre-erection outfitting is done by the foreign yards. Summers [1993] noted that for Japanese naval ship construction engine room machinery is built up almost entirely in the shop and installed later.
    - Sheet metal work. Foreign yards install much more sheetmetal on-unit or on-block when the block is inverted.
    - Woodwork. All surveyed foreign yards erect the superstructures and deck houses almost completely outfitted. Modular cabins and sanitary spaces are also used extensively.
    - Electrical. Foreign yards install and hook up all major electrical equipment and lights before launch. Cables are pulled on block with those that extend to adjacent blocks cut to length and stored for pulling on-board.

  - Painting. A number of problems were noted in U.S. yards with painting. The most important were (1) weld through primers were not used, (2) because of the length of time in storage or in work, blocks go through a second blast and prime, necessitating the installation of many items in the upright position or on-board, and (3) most finish painting is done after erection, necessitating a large amount of staging.

- Activity (G.) Design/Drafting/Production Engineering/Lofting. The greatest average differences in technology occur in this group. Even where U.S. yards score well (steelwork coding and parts listing) the foreign yards have a higher level. The survey authors cite this as an example of where U.S. yards have superior equipment but do not use it as effectively as their competitors use less sophisticated equipment. U.S. yards are lower in technology level of at least 0.9 in all elements listed below.

  - Ship design. All U.S. yards have some design capability but they are severely limited in commercial capability.

  - Steel work and Outfit drawing presentation. Foreign yards prepare drawings to support the way in which the work is performed. Drawings are related to work station/zone/stage and include all items to be performed by all trades.

  - Production engineering. The major advantage of the foreign yards is that they have developed physical and procedural standards which have been accepted by flag states and classification societies.

  - Design for production. U.S. yards apply producibility efforts after contract signing, but this needs to be moved to earlier design phases. Foreign yards are particularly advanced in design for production for outfitting.

  - Dimensional and quality control. U.S. yards have started collecting dimensional information for steel working, but have not fully analyzed the data, nor has the information been collected for outfit work. Foreign yards have established steel and outfit work stations which produce identical, or very similar products. Comprehensive standards have been implemented, and they have a system of self checking at every stage and continually assess whether the system is in control.

- Activity (A.) Steelwork Production. U.S. shipyards are not superior in any element, but are equal in one (Plate Stockyard). Major differences exist in:

  - Stiffener cutting. Performed by hand marking and hand cutting.

- Sub-assembly. Produced in random shop locations where other work, such as outfit steel items, are produced.
- 3D Unit assembly. U.S. practices include assembling where space is available, adding individual stiffeners to web and pulling shell plate around, adding curved stiffener panels to webs, erection outside, leaving excess stock on plates, and using welding procedures which result in significant distortion.
- Outfit Steelwork. Often produced in locations determined by where space is available. No group technology is used.

• Activity (B.) Outfit Production and Stores. U.S. yards are superior in the maintenance element and are very close in the other elements except for two elements where significant differences occur.

  - Sheet metal work. U.S. shops are very well equipped but none is organized for group technology. They all appear to produce items which could be obtained cheaper from outside.
  - General storage. Warehouses in U.S. yards are large and well run. The difference is that they tend to store tremendous amounts of material and equipment, whereas the foreign yards hold low levels of stock and concentrate on just-in-time delivery.

• Activity (H.) Organization and Operating Systems. All surveyed yards scored high, but foreign yards were consistently better, except for purchasing. Two areas in which foreign yards were significantly ahead were:

  - Organization of work. This relates to the flexibility and supervision of the work force. Foreign yards have more cross trained workers, and perform the work in workstations or zones where supervision is by workstation leaders rather than by trades.
  - Contract scheduling. Foreign yards link strategic and tactical planning using computer systems which allow direct interaction between the two levels.

• Activity (C.) Other Pre-erection Activities. The yards are quite close and the technology levels are quite high for the group as a whole. Significant differences are in Outfit Parts Marshaling in which the U.S. yards excel, and Unit and Block Storage in which the foreign yards are furthest ahead.

• Activity (E.) Layout and Environment. Both foreign and U.S. yards scored low in this group. With the exception of one U.S. yard and two foreign yards, the

layouts and material flows are constrained by the sites and ad hoc way in which the yards have grown.

b. Labor Productivity

The study team also assessed the labor productivity of the surveyed U.S. yards and three of the foreign yards. The measure of productivity used was cost in U.S. dollars per Compensated Gross Ton (CGT). CGT is derived from gross tons based on the effect of size and complexity of each ship type on work content. A standard system for calculating CGT was adopted by the Organization for Economic Cooperation and Development (OECD) in 1984. The survey authors estimated CGT for naval ships for the study. Cost per Employee Year was derived using total salaries, social costs, general and administrative (G&A) cost, fixed and variable overhead, direct and indirect shipyard employee years, and direct and indirect subcontract employee years expended on shipbuilding for a 3-year period for foreign yards and a 5-year period for U.S. yards. CGT was derived for ships produced during the same three or five year period. Productivity data were recorded over five years for the U.S. yards because of the greater throughput of the foreign yards. Cost/CGT was then calculated as Cost/CGT = (Cost/Employee Year)x(Employee Year/CGT).

Average COST per CGT and labor hours per CGT for the U.S. and foreign yards are shown in Table 31. The survey authors note that the data are not exactly comparable. During the observation period, two of the U.S. yards undertook a significant amount of ship repair work, and some yards performed "planning yard" work that produces spent labor hours but no production.

Table 31. Comparison of Productivity for U.S. and Foreign Shipyards

Measure	U.S. Yard Average	Visited[a] Foreign Average	All[b] Foreign Average
Labor-Hours Worked Per Year	1,829	1,805	1,963
Labor-Hours/CGT	184.8	40.0	88.0
Cost/Employee-Year	$52,500	$63,455	$48,690
Cost/CGT	$5,314	$1,121	$1,296

Source: Storch, A&P Appledore, Lamb, 1994.
[a] Three surveyed foreign yards.
[b] Foreign yards comparable in size to the U.S. yards.

c. Summary of the Technology Survey

None of the U.S. yards build commercial ships, but this does not account for most of the major differences. Summers [1993] noted many observations for Japanese naval ship construction which seem to agree closely with those of the survey team. Two exceptions may be in Warehousing and in Design and related activities. The large amount of parts and equipment storage in U.S. yards may be related to GFE to some extent. Success in the commercial market requires a more advanced design organization which is linked to all other yard activities. U.S. yards have not had the incentive to develop such design groups.

Although the survey addressed commercial shipbuilding competitiveness, most of the elements are applicable to naval shipbuilding as well. The survey authors summarize the requirements for world class commercial ship competitiveness including the need for the following planning documents:

- Business Plan that focuses on the product they intend to build, their capacity, targeted output and build cycles, and the need to develop targets for costs and pricing policy
- Shipbuilding Policy that addresses facilities development, productivity targets, ship definition strategy, production organization and methods, planning and contract procedures, and make/buy or subcontract policies
- Marketing Plan that targets the owners of the ship types and sizes which are identified in the business plan in a proactive manner.

These factors will be addressed in more detail in the following section. The following summary addresses the major survey findings which are related to construction of naval and commercial ships. It is of interest that many of these areas were noted by Summers [1993] relative to naval ship construction. These include:

- Design/Drafting/Production Engineering/Lofting. The design organization of the foreign yards have greater capability and are part of a total system which is fully integrated with the rest of the yard. The survey indicates that U.S. yards are deficient in the implementation of concurrent engineering, and engineering products oriented to how and where the work is to be performed.
- Accuracy Control. This an area which is critical to efficient ship production. U.S. deficiencies are indicated by the findings concerning steel, outfit and painting. Without a statistical accuracy control system that is carried out at all

levels down to the individual mechanic, it is impossible to know if the system is in control, and to realize potential savings in cost and build time.

- Material Control and Purchasing. U.S. yards are well equipped to store and manage large inventories of supplies and equipment, but they do not practice just in time material management. Partnering or other supplier relationships which enable the yard to build a data base of suppliers and their performance are not routine. These are areas which need to be addressed by the yards and the Navy.
- Second Blast and Prime. This is an area which impacts the amount of on-unit and on-block outfitting that is possible and therefore affects the entire production process. It is not carried out by any world class foreign yard and should be unnecessary.
- Outfitting. Only one of the surveyed U.S. yards had collected data on an outfit manufacturing or installation procedure in order to implement a self checking statistical process control system. Outfitting is consistently performed later in the build cycle in U.S. yards and much of it is done with the block in its final orientation. U.S. yards do more electrical outfitting on board than should be necessary. Standard machinery and accommodation modules, and outfitting of deck houses and superstructure prior to erection should be the rule. The modularization of on board services, and early outfitting of electrical and piping systems so they could be hooked up to shore services would reduce cost and clutter on board.
- Painting. This is an area where the Japanese are making large investments in order to improve productivity and quality. Blocks should be finish painted before erection in order to save corrosion control costs and eliminate the need for staging.

The survey team's productivity data are difficult to evaluate, primarily because of the teams caveats concerning repair and planning yard hours. Labor-hours per CGT of 22 percent for the visited foreign yards relative to U.S. yards appear low compared to other studies and trip reports, but may be reasonable considering the technology results. The all foreign average of 48 percent looks to be more in the ball park, but the yards in this sample include many that are not world class yards. Even if the visited yard results are off by a factor of one, there is certainly cause for great concern on the part of the U.S. shipbuilding community.

The survey results are not entirely negative, however. U.S. labor rates are competitive with those of the major shipbuilding countries other than Korea, and most of

the technology gaps are in the area of management practices, or other soft technologies. Consequently, significant improvement in competitiveness is possible without major investment in hardware or facilities.

3. World Class Ship Production

a. Group Technology Shipbuilding

The basic concept underlying world class shipbuilding is Group Technology (GT) or Family Manufacture (FM). GT began as an attempt to develop a more efficient system of classification and coding for use in the management of industrial processes. However, it has developed into an innovation in the broader field of management, not just a technique for keeping track of material, parts and assemblies. Group technology is a means of bringing the benefits of mass production to high variety, mixed quantity production. A major objective of GT is to reduce the inventory of work in process to only what is needed. GT was first applied to shipbuilding by the Japanese. The concepts and applications were brought to the United States primarily by Lou Chirillo in a series of NSRP publications. For a detailed description of GT shipbuilding the reader is referred to Storch, Hammon, Bunch, Moore [1995].

Group technology applied to shipbuilding uses a product-oriented work breakdown structure and zone oriented planning, scheduling and production. The Navy uses a systems-oriented work breakdown structure (SWBS) to subdivide the ship by system and weight group. However, efficient production requires a classification system which is oriented toward interim products. A product-oriented work breakdown structure (PWBS) is such a classification system. Classification by product aspect relates a part or subassembly to a system and zone of a ship design and also to work processes by problem area and by work stage. Parts and subassemblies are grouped by permanent characteristics and classified by both design and manufacturing attributes. The classification system also specifies parameters, such as form, dimensions, tolerances, material, and types and complexity of machinery operations.

PWBS first divides the shipbuilding process into three basic types of work--hull construction, outfitting, and painting--each of which is associated with unique manufacturing problems. These are further subdivided into fabrication and assembly. The PWBS then classifies interim products by required resources: material, manpower and

facilities. The third classification is by product aspect: system, zone, problem area and stage. The work is then organized according to zone, problem area and stage, where:

- **Zone**—an objective of production which is any geographical division of a product, *e.g.*, cargo hold, structural block or outfit unit or ultimately a part or component.
- **Problem area—**a specific type of work, involving the use of similar production techniques, tools and worker skills. Problem areas may be determined by:
  - Feature, curved versus flat blocks, steel versus aluminum,
  - Quantity
  - Quality of workers or facilities required
  - Kind of work, e.g., cutting, bending, painting.
- **Stage**—a division of the work by sequence, e.g., before or after turning a block over, outfitting on unit, on block, or on board ship.

Because inherently different types of work are required, the PWBS must accommodate the following zone-oriented methods:

- Hull block construction method (HBCM)
- Zone outfitting method (ZOFM)
- Zone painting method (ZPTM).

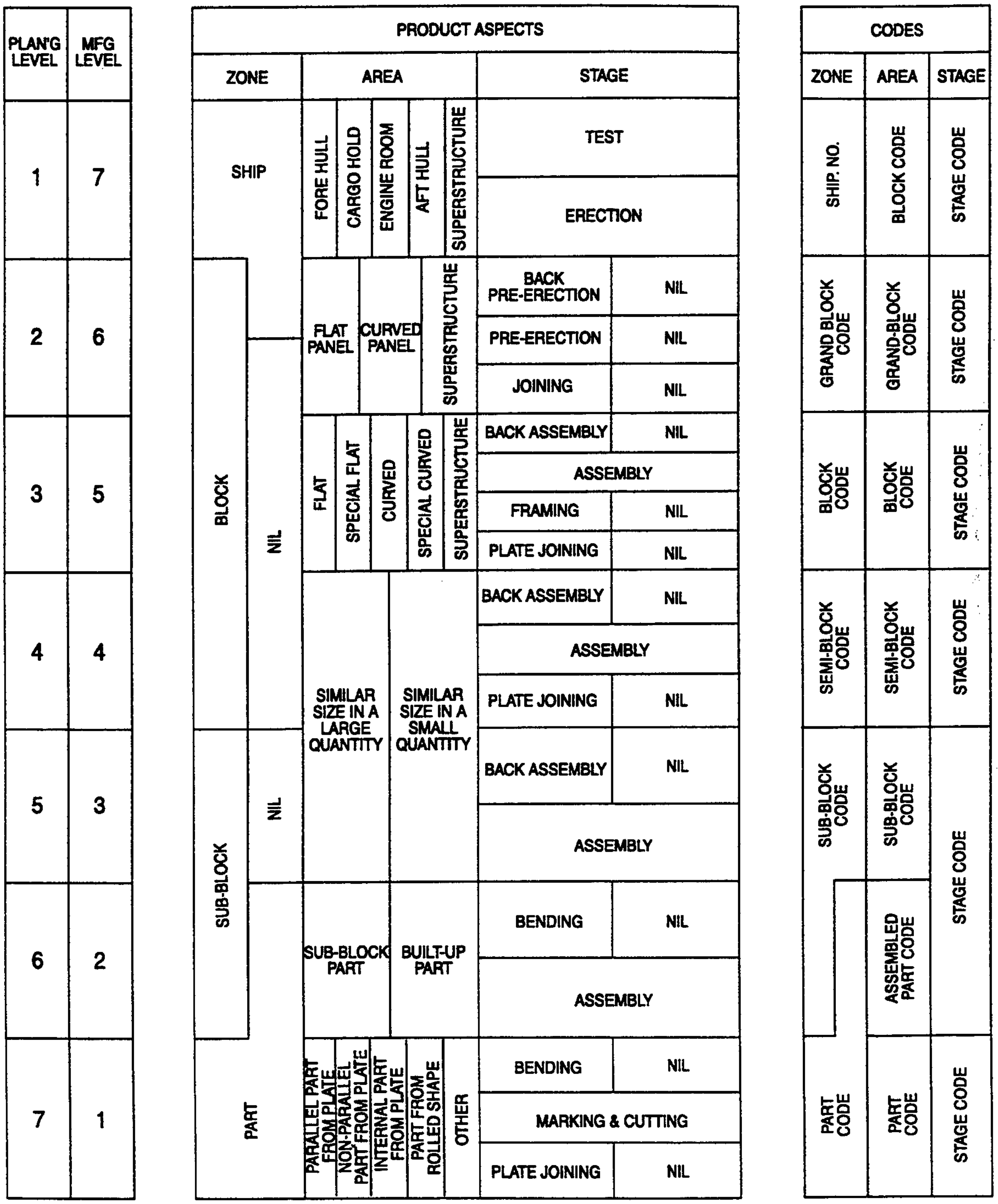
The basic structural unit is the block, which must accommodate the above methods. Once interim products are subdivided into families with similar manufacturing characteristics or problem areas, the work is accomplished at work stations, by cross trained crews, at the most advantageous stage, e.g., installing ducting or cables after block turnover when the work can be done down hand versus overhead. This also implies outfitting at the earliest possible stage, when the structure is open and accessible. The most efficient stage for outfitting is on-unit in the shop. For example, entire machinery spaces or engine assemblies may be assembled, outfitted and tested on the shop floor (on-unit) and moved into the hull structure blue sky. The second most efficient outfitting stage is on-block before the block is moved to the building dock or way and welded into its final location. The final and most expensive stage for outfitting is on-board after erection.

A basic principle of the process is for material to move in a logical sequence from the shop to the erection area via process lanes, with each interim product arriving at subsequent stages just as it is needed. A process lane is a group of work stations designed to produce a family or families of products which require similar processes. Process lanes may be real or virtual, and are organized according to problem area, stage and work content, so that the line is balanced, analogous to an assembly line. A second basic principle is that a self checking system, using feedback is in place, such that interim products arrive at the next stage ready to be processed. This means that assemblies and blocks fit together without additional cutting or distortion removal. It also means that work packages must be sized optimally according to resource requirements. This implies a statistical accuracy control system based on day to day observations at all levels with feedback to the preceding stages. When these principles are met the process is said to be in control.

Figure 18 shows typical HBCM groupings by product aspects for seven manufacturing levels. The horizontal combinations characterize the various types of work packages that are required for the work to be performed at each manufacturing level. Vertical combinations of the various types of work packages denote the process lanes for hull construction work flow.

b. U.S. Shipyards and Group Technology Ship Production

U.S. shipyard productivity and technology were compared with foreign competitors in subsections C-1 and C-2 above. Following are some observations of the IDA study team during visits to five major Navy shipbuilding yards. All of the yards practice GT methods to some extent and the HBCM is fairly advanced. This is not necessarily the case for ZOFM or ZPTM.



Source: [Storch, Hammon, Bunch, and Moore, 1995] p. 71.

Figure 18. HBCM Classification by Product Aspect

Cross Training. One observation common to all of the yards is their organization for production. U.S. yards are organized by function rather than by product, and supervision is by trade rather than by work station. Only three of the yards have programs for cross training workers. One yard has had a program of cross training in place since 1987 and extends cross training, during and after regular work hours, to new hires as well as journeymen. The other two yards tie cross training to pay increases, and generally extend it only to more senior personnel. These yards put those employees, who are accepted into the program, through a full training program so they can become fully qualified in all aspects of their second skill. It is noteworthy that one of these yards is in the process of organizing supervision by product and zone, with several trades working together under the supervision of a team leader who is responsible for a zone. We were unable to determine if this system would extend down to problem area and stage.

Process Control. All of the yards visited have some industrial engineering staff. However, all are deficient in the area of statistical accuracy control compared to world class foreign yards. Most of the effort in this area is an outgrowth of a program to control welding distortion. We found no evidence that measurements or analyses had begun for outfitting in any of the yards. Two yards have recently begun a fairly intensive effort toward implementing a distortion control program, and one has the beginning of a statistical accuracy control program in place. However, the most advanced yards have a functionally organized accuracy control division rather than accuracy control being integral to production and organized by product and work station. In general the yards do not have self checking systems whereby the results of measurements are analyzed and fed back into the system in a timely manner. In at least one yard the only feed back on a regular basis is to the next ship in the sequence.

Outfitting by Stage in U.S. Shipyards. A major technology problem cited by Storch, Appledore, and Lamb [1994] was that work in U.S. yards--particularly outfitting--was consistently delayed to later stages of construction than in foreign yards. The usual measure of this is the percentage of work done on-unit, on-block and on-board. It is generally true that productivity decreases as work is delayed to a later stage. It is not clear just how much for any given shipyard or type of ship. One difficulty is that the data are proprietary to each yard and generally unavailable in sufficient detail to draw meaningful conclusions. It also seems probable, considering the state of accuracy control in U.S. yards, that the shipyards themselves do not really know the full effect of moving

work to a later stage. The direction of change is known generally, but not necessarily the quantitative effect by stage and type of work. Without systematic data collection, and analysis of productivity values of work packages, the most we can expect is to move the accomplishment of work in the right direction.

It must also be borne in mind that, in the calculation of work package productivity value, time is one of the variables, along with resources and quality. This means that as work is moved to an earlier stage, work package content must be adjusted so that process lanes remain balanced One of the yards we visited noted that a considerable amount of work was shifted to on-unit and on-block for a particular hull. The reason, however, was a delay in the launching of the preceding ship. The extent to which this resulted in increased productivity is problematical.

Even so, the percentage of work moved to an earlier stage is a useful measure of productivity, however imperfect or well known. Estimates of productivity increases with outfitting at an earlier stage vary a great deal. Spicknall and Wade [1992] estimate the labor-hours for outfitting on-block to be 4-6 times that required for on-unit, and on-board to be greater than on-unit by a factor of 7-12. U.S. shipyard estimates collected by a member of the IDA study team place this at closer to 2-4 for on-block relative to on-unit, and 3-5 for on-board relative to on-unit. The latter estimates imply that moving work from block to shop could reduce labor-hours by a ratio of 1/2 to 1/4. If work is moved from ship to block, labor-hours could be reduced by 2/3 to 4/5. Perhaps the most systematic and rigorous estimates have been compiled by [Borchers, Kraine, Thompson, and Wilkins, 1992] and [Wilkins, Kraine, and Thompson, 1993] in conjunction with producibility studies. Wilkins, Kraine, and Thompson [1993] also report the details of a computer program and productivity factors used for comparing producibility changes made at different stages of production. The program, called CEOPS, uses engineering standards based on a bottom up, production engineering approach to estimating costs in ship production and repair. Table 32 shows estimated labor difficulty factors for eight different stages of construction and the typical, or standard, location for each stage. These factors represent "an amalgam of the work stage difficulty data obtained from various sources. Revisions to the work stage factors, based on later and expanded measurements, are anticipated." [Wilkins, Kraine, Thompson, 1993]

Table 32. Construction Stages and Difficulty Factors

Stage	Location	Difficulty Factor
Fabrication	Shop	1.0
Pre-Paint Outfitting	On Platen, Hot	1.5
Paint	Paint Shop/Stage	2.0
Post-Paint Outfitting	On Platen, Cold	3.0
Erection	Erection Site	4.5
Outfitting	Erection Site	7.0
Water Borne	Pierside After Launch	10.0
Test and Trails	Pierside and Underway	15.0

Source: [Wilkins, Kraine, and Thompson, 1993].

For those yards for which we were able to obtain data, the average outfitting on-unit varied between 15 percent and 30 percent for Navy ships. On-block was between 15 percent and 55 percent and on-board between 15 percent and 70 percent. All of these data varied across ship type as well as across yards and the greatest variation was by ship type. This may indicate that the variation is influenced by Navy design and installation restrictions as well as by desired yard production policy. For example, reduction in on-board outfitting is limited by requirements for brazed and welded pipe joints, and by restrictions on cable splicing. Pipe and electrical outfitting represent the two primary outfitting trades, accounting for approximately 20 percent and 30 percent respectively by weight. These are followed by hull outfitting (12 percent), and sheetmetal and machinery (6-7 percent). Other outfitting accounts for approximately 25 percent.

Navy painting requirements and U.S. yard practice cause important bottle necks, which greatly influence the amount of work that can be moved to an earlier stage. According to Summers [1993], requirements for a second blast and paint between block outfitting and erection greatly increase the amount of on-board outfitting required in U.S. warship construction compared to the Japanese Kongo. Painting and fitting on-board is also increased by the practice of leaving excess material which has to be removed during erection.

The extent to which current U.S. outfitting practice is caused by Navy requirements is not known. However, those yards which provided data anticipate substantial progress within the current system. The yards which provided data have effected improvements, since the mid to late 1980s, which have decreased the amount of outfitting on-board by 40 percent to 75 percent for Navy ships. Those yards planning to

enter the commercial market, or who are producing commercial like ships, expect to decrease on-board outfitting by up to 85 percent relative to commercial ships built in the 1970s. During our visits to shipyards, personnel from only one yard stated that they had made no changes in the last 5 years to the percentage of outfitting on-unit/on-block/on-board. In this one instance, the yard personnel stated that they had no idea what the current percentage of each was for their yard.

Investment in Facilities and Technology. The MARITECH and Title XI programs, along with a desire of the major yards to remain competitive in the military shipbuilding business, have given considerable impetus to facility improvements. Although not all of the yards are committed to commercial production, all are participating in the MARITECH program, and many of the facility and organizational improvements lend themselves to commercial shipbuilding. At least one yard, which is seriously attempting to enter the international commercial market, is also investing $120 million in facilities aimed at that market, including a dry dock extension, dual use covered outfitting area upgrade, and robotics. Nearly all of the yards are devoting considerable attention to design and CAD/CAM/CIM development. Nearly all of the yards stated that their design and CAD/CAM projects were intended to support an improved total yard information system and concurrent engineering. These design improvements, which generally began as efforts to improve producibility, are also important to eventual entry into the international market, both commercial and military. Three of the yards are actively pursuing foreign military sales.

All of the yards are investing, to some extent, in steel work improvements, including semi-automatic panel lines and welding, one sided butt welding on panel lines, the ability to handle 52-foot plates, CNC plasma burning equipment, robotic cutting and welding equipment, and improvements in steel yard marshaling and material flow.

A tour of the yards, with one exception, impresses the visitor with the cleanliness compared to what was the rule a decade or so ago. Shipyards have always been considered as places where the work is noisy, dirty, dangerous and generally unpleasant. Noise is still a problem, but zone construction methods have reduced the danger and most of the yards we visited seemed to be somewhat cleaner. One in particular, has concentrated on the environment, including cleanliness and painting the overheads of enclosed areas white. The effect is a much more pleasant, well-lighted and safer work place. This same yard has also worked out a union agreement which has the effect of a

partnering arrangement. The agreement provides more security for the work force, and union representation with regard to company policies. The result is a more cooperative work force seemingly dedicated to the success of the yard.

All of the yards are working with foreign world class shipbuilders, either through partnering, or consulting arrangements. There appears to be a different philosophy associated with these efforts than was the case in the early 1980s. At that time all of the major yards hired Japanese consultants and attempted to import Japanese methods. This technology transfer effort, along with the NSRP, did a great deal to raise the awareness level of U.S. yards and resulted in the implementation of product-oriented methods. However, there never was a complete understanding, or acceptance of the total system. Technology transfer was oriented to particular processes which in many cases, were taken out of the context of the overall system where they were successfully applied by the transferring yard. Many technology recipients seemed to pick and choose those production and management practices which suited their operation, rejecting the rest.

In the current round of technology transfer, the recipients appear to have a better understanding of the basic concepts of product-oriented ship production, and that each process is part of a total system. Some yards are now sending more people to the partnering yards for a long enough period to gain real understanding, rather than only having foreign consultants instruct them at the U.S. location. The statement was made at one of the yards that we are looking for understanding rather than just learning how to accomplish a given technique or process. It is early to tell, but it does appear that many of the on-going facility and technology investments are more focused and there is a better understanding that high technology by itself is just a faster, neater way of doing something. Unless the improved process fits smoothly into the overall production plan nothing changes.

Daidola, Parente and Robinson [1994] analyzed the effect of concurrent engineering and various production innovations on producibility and labor costs for double hulled tankers. The study, identified three areas which they concluded were ...."where the greatest gains may be possible to make U.S. shipyards more productive and more competitive on a world scale." These areas were improved automation, accuracy control and the design processes. Their findings seem to indicate that the investment programs and management innovations of the major U.S. yards are on track, except for accuracy control. It appears that this is an area which needs to be examined much more thoroughly

by the U.S. shipyards. More importantly, a much better understanding of accuracy control—how it is done, and by whom, as well as what it should accomplish—is necessary.

4. Total Commitment and Shipyard Strategy

The U.S. shipbuilding industry and production practices are characterized by risk-averse strategies which respond to uncertainties in the product and resource markets. The major shipbuilders are implementing technology transfer and investment policies with the goal of improving productivity. These programs are essentially being carried out piecemeal in response to opportunities to improve particular processes as they become apparent. This is not to say that the yards do not look at the big picture, nor that they do not have an overall long range plan. Rather, they are responding to the market and the market is still the U.S. Navy. The Navy, along with OSD and Congress, therefore must play a major role in future advances in production process improvements and productivity increases.

The consensus of Navy managers we interviewed was that commercial production would produce many benefits for the Navy shipbuilding program. The spreading of overhead and greater utilization of fixed capital are the most obvious. There were some reservations, however. One frequently expressed concern was whether Navy work would get first priority, and whether any relaxation of Cost Accounting Standards (CAS) or the Federal Acquisition Regulations (FAR) would result in contractors taking advantage of the government. Similarly, questions were raised with regard to changing Navy established practices in order to realize potential productivity gains. Navy personnel tend to be averse to giving up any control over design, quality testing, or military specifications/standards for fear that quality will suffer. They are likewise reluctant to relinquish control over the procurement of certain equipment and information (GFE/GFI).

The study now examines what shipyards can do to improve production practice in the absence of changes in the government's way of doing business. Clark and Lamb [1995] address the benefits of a Build Strategy for specific ship programs. Lamb, Allan, Clark, and Snaith [1995] expand on the use of a Build Strategy as well as other "world class" shipbuilding processes to improve productivity in U.S. shipyards. A build strategy is defined as:

> "an agreed design, engineering, material management, production and testing plan, prepared before work starts, with the aim of identifying and integrating all necessary processes." [Clark and Lamb, 1995]

Clark and Lamb [1995] apply the build strategy primarily to commercial ships. However, a build strategy is also applicable, and necessary, for efficient production of Navy ships. Key elements of a build strategy, applicable to commercial or Navy ships are:

- Zone definition
- Hull block definition
- Dimensional reference system
- Alignment procedures for propulsion equipment
- Molded lines definition
- Accuracy control panel
- Required tolerances
- Material and design selections—hull structure
- Material and design selections —deckhouse structure
- Hull outfitting scheme
- Deckhouse outfitting scheme
- Machinery space outfitting scheme
- Definition of information requirements for design and production
- Preliminary make-buy assumptions
- Basic key event schedule development.[3]

The build strategy is contract specific and supports the company Business Plan and Shipbuilding Policy. The shipyard business plan sets out the company's long range goals and how it plans to achieve them. This should include the desired product mix and a marketing plan for achieving it, shipyard capacity, targets for cost and a pricing policy.

The Business plan is supported by a shipbuilding policy. This policy defines the organization and build methods required to produce the product mix in the Business Plan.

---

3 These elements are adopted from Wade [1995]. He included two additional elements (1) the establishement of industrial base capabilities/limitations, and (2) the creation and adoption of a PWBS. These are applicable to a Generic Build Strategy, but in general should be determined as part of the shipbuilding policy.

The Shipbuilding Policy should include decisions on facilities, productivity targets, and the production organization. The shipyard policy should specify a PWBS and how this fits in with the design, production, planning, and material control organizations. The business plan and shipyard policy are the guiding documents for the build strategy.

The major U.S. yards are currently at a cross road with regard to product mix. On the one hand they are being asked to enter the commercial market as one means of preserving the shipbuilding base. However, they recognize who their customer is now and appear to be unwilling to bet the yard on being able to successfully compete in the international market. At least one yard CEO has publicly stated that their business is building Navy ships and they intend to continue doing so. The question arises for the industry whether a dual purpose, Navy and commercial, yard can be viable. Lamb, Allan, Clark, and Snaith [1995] contend that it cannot and cite the experience of European yards that have tried to do so and failed. However the Japanese have successfully accomplished this with side-by-side yards that use the same engineering, material control, finance and some production facilities. At least one U.S. yard stated a willingness to try. The question is whether the inefficiencies inherent in having the government as a customer can be eliminated from the commercial side of the business. The alternative is for the government to become a world class customer as envisioned by the current Acquisition Reform program.

D. STANDARDIZATION AND NAVY INITIATIVES

This section describes two closely related Navy initiatives: (1) Affordability Through Commonality (ATC) and (2) Mid-term Sealift Ship Technology Development programs. Both these programs address producibility and affordability.

1. Affordability Through Commonality

The ATC project office in NAVSEA was established in August 1993, but its roots go back to the SEAMOD concept initiated in the late 1960s. SEAMOD envisioned a limited number of generic hulls, which could be equipped with weapons systems selected from a catalog of standard modules. Although the concept was never adopted by the U.S. Navy, it found practical application at Blohm and Voss--a German shipbuilder--in the form of the MEKO frigate. Blohm and Voss markets MEKO combatants worldwide, based on

a standard hull and a selection of weapons and equipment modules that can be selected to individualize the ship for a particular mission. To date, 38 MEKO vessels have been built.

The ATC initiative was begun with the intention of "....improving the process by which the Navy, with industry's help, designs, acquires, and provides lifetime support for ships used in national defense." The ATC program goal is to reduce the cost of ship acquisition and in-service support. This goal is to be achieved through equipment modularization, increased equipment standardization, and process simplification. [Bosworth and Hough, 1993] The ATC is part of the National Shipbuilding Initiative established by Title XIII, National Defense Authorization Act, 1994. [Hough, 1995] The Mid-term Sealift Ship Technology Development Program is a series of R&D tasks being carried out by the Ship Technology Office of the Naval Surface Warfare Center, Carderock Division under the direction of OPNAV (N-42) and NAVSEA (03R).

These programs are well documented and well known throughout the shipbuilding community. We briefly summarize them here because of their importance and far reaching implications for the future of Naval ship production.

a. The ATC Concept

The ATC concept includes three primary elements; (1) common modules/ interfaces across the fleet, (2) increased equipment standardization, and (3) process simplification.

Common modules promote parallel efficient construction and outfitting in a shop environment, and more affordable upgrading. Prototype modules have been developed for crew habitability spaces (quarters, sanitary modules), machinery/auxiliary systems [e.g., Navy Standard Fire Pump; Heating, Ventilation and Air Conditioning (HVAC) modules; and reverse osmosis desalination modules], and combat systems/C^4I systems (e.g., a 5-inch Gun module). Habitability modules are common in cruise ship construction and facilitate off site joiner work. Machinery/auxiliary system and combat/ C^4I system modules would facilitate design, acquisition and intermediate maintenance and future upgrades. Systems could also be used in multiple ship classes.

Equipment standardization is inherent in having common modules, but extends further and to diverse equipment down to piece parts. This element of ATC borrows from the Ship System Engineering Standards (SSES) program of the 1980s which facilitated

both construction and maintenance by standardizing families of equipments, such as centrifugal pumps. SSES reduced the number of parts, assemblies, and specifications to a minimum. For example, by developing a family of standard fire pumps the Navy reduced the number of pumps in the fleet from 70 to 8. [Tibbetts, Keane, Covitch, and Comstock, 1993] In order to realize real savings and simplify the process, standardization would also take advantage of commercially available equipment and rely on commercial standards when possible. The standardization of systems and parts could effect the realization of a system comparable to that used by the British for many years. The British have long used a system whereby components are certified and stamped with a crown. Parts bearing the crown are then guaranteed acceptable for the intended use.

Process simplification depends on the concepts of modularity and equipment standardization. The processes to be simplified include production, logistics and requirements definition. According to Bosworth and Hough [1993], process simplification includes the strategies, policies and procedures to implement the following:

- Fewer, more standard systems designs [especially for hull, mechanical, and electrical (HM&E) systems]
- Elimination of unnecessary military specifications and standards
- Procurement of equipment at the fleet level
- Generic and engineered build strategies at the fleet level
- Improved/efficient assembly of major equipment/systems
- More production-oriented distributed system architectures
- Increased parallel assembly/test of equipment and systems during ship construction
- Fewer equipment/systems to support (i.e., spares and training)
- Replaceable components/subassemblies to ease maintenance
- Upgradable systems to ease modernization (combat systems)
- Digital data use and reuse across discipline lines and across the current boundaries of design, acquisition, production and in service engineering.

2. Mid-Term Sealift Ship Technology Development Program

The Mid-Term Sealift Ship Technology Development Program (MSSTDP) addresses ship producibility. It is a cooperative program involving shipyards, university

personnel, vendors, design consultants, and the NAVSEA Shipbuilding Support Office, Philadelphia. Objectives of the program include construction contract cycle reductions of 40 to 60 percent, initial acquisition cost reductions of 15 to 25 percent, replacement of MILSPEC equipment with commercially acceptable versions, enhanced CAD capability with on-screen "lessons-learned," creation of equipment arrangement and packaging concepts, and to identify and recommend candidate activities for change within the NAVSEA acquisition process. [Wade, 1995] Projects include:

- Infrastructure Study in Shipbuilding (ISIS) [Wade and Karaszewski, 1992]
- Generic Build Strategy [Wilkins, Singh, and Cary, 1995]
- Product-oriented cost estimating
- Engine room arrangement modeling (ERAM)
- Commercial standards development
- Auxiliary Ship Acquisition Model (ASAM)
- CAD-2 Producibility Software Module.

Participation of shipbuilders, U.S. and foreign, is a strong plus for the MSSTDP. Shipyards, vendors and design agents, along with the USCG and the University of Michigan are major participants in the four primary producibility studies (ERAM, Commercial Standards, SSAM and CAD-2 tools).

E. FINDINGS

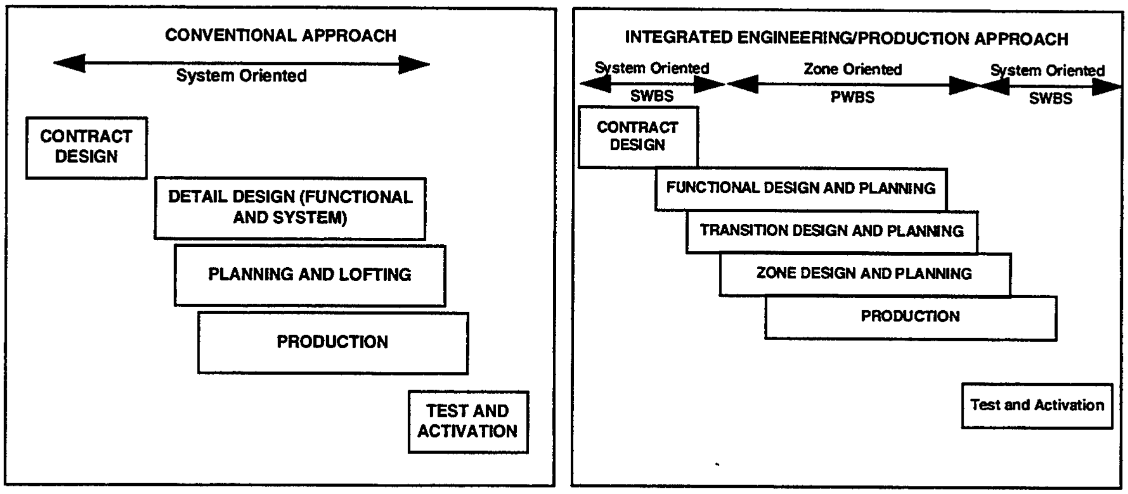
As stated at the beginning of Chapter II, design and production are closely related and should not be separated in practice. Consequently, this section covers concepts analyzed in this chapter as well as in the previous one. The industrial performance of the U.S. shipbuilding industry is determined by complex economic and political interactions. The market structure is characterized by a monopsonistic buyer (the U.S. government) and oligopolistic sellers. The product market is characterized by cyclicality and resulting risk averse behavior on the part of the industry. The reliance on the U.S. government has resulted in a labor intensive industry, the effects of which are amplified by restrictive government acquisition regulations. All of these factors affect the investment patterns and production methods chosen by the firms within the industry. Although a great deal of effort is being expended to encourage the industry to enter the world shipbuilding market,

there seems to be no compelling reason for them to do so right away. As long as the Navy continues to pay a premium to acquire ships under the current rules, it is likely that the industry will continue to respond to their primary customer.

Uncertainty and risk aversion drive production, and the adoption of modern production methods is encouraged by a market which rewards efficiency. The current system of unilateral contract cancellation, option ships, and dual sourcing adds to the uncertainty of the market and dual sourcing reduces the throughput for successful bidders.

The Navy has initiated many innovative programs which have the potential of reducing the shipbuilding construction cycle time and reducing life cycle costs. The DAC project, ATC, the LPD 17 program office initiatives, and the Mid-Term Sealift Ship Technology Development Program all provide practical answers to making Navy ship production more cost-effective. However, all of these programs are structured around current NAVSEA, DoD and Congressional policy. Efficient ship production requires revolution rather than evolution. The U.S. Naval shipbuilders are unlikely to become world class until the U.S. government becomes a world class buyer.

The practice of NAVSEA retaining strict control over design, through contract design, inhibits shipbuilders from developing fully capable design organizations which are integrated with production, accuracy control, planning, and production or material control. Inviting potential bidders and suppliers to be part of the design IPPDT, and the Generic Build Strategy go a long way toward making producibility a driving force in Navy ship designs. However, these are still only ways to reduce the undesirable effects of the shipbuilder not having control over contract design--what an economist would call a "second best" solution. Figure 19 shows the design stages for an integrated engineering/production approach to product oriented ship design and construction compared with the conventional Navy approach. This figure appears in several briefings of the GBS and in [Bosworth and Hough, 1993]. The product oriented approach (b) is in close agreement with standard GT shipbuilding practice. Although the figure is only a schematic, the zone oriented arrow should perhaps be extended in both directions. The main difference between the approach as presented and world class is in who does the contract design. If the contract design were done by the winning shipyard (industry team) as part of a design competition, there would be no need to extend the GBS beyond the preliminary design phase. The bidders could then prepare contract designs based on their own facilities, build strategy and supplier arrangements.



Source: [Hough, 1995].

Figure 19. Comparison of Conventional Navy Design/Production with an Integrated Engineering/Production Approach

The current practice of the government retaining control over procurement and integration of the weapons systems removes control of the total ship production process from the shipbuilder, and inhibits organizing for integrated product oriented design and production. Joint ventures such as the Trinity-McDonnell Douglas King Cobra team and those formed to compete for the LPD 17 include firms experienced in dealing with electronics and weapons systems. Such partnering would enable the prime contractor to assume responsibility for procuring and integrating the weapons system, and would thus offer an alternative to extensive reliance on GFE.

The current design cycle and requirements for open competition further dilute the prime contractor's control over the production process by necessitating Navy procurement of long lead items. One alternative is to select the prime contractor prior to contract design (allocation). However, it is not clear that this would be an acceptable course of action. It has been done in the past, but it is unlikely that Congress or the courts would allow the complete absence of competition from the process of selecting the prime contractor. The feasibility of each bidder identifying long lead time items as part of their contract design, with orders being placed after contract award should be investigated. This was essentially the design strategy used for the FFG 7, considered to be a very successful program by operators and the Navy design organization. [Tibbetts and Keane, 1994] Any lost time between contract signing and keel laying (the time generally determined by the delivery of long lead time items) would not affect total cost nearly as

much as the current excessive construction time for each ship. Partnership arrangements between the bidders and suppliers of long lead items would also facilitate the elimination of this part of GFE.

Several additional findings regarding production follow:

- Unique government contract requirements and management practices impose a premium on all defense procurements including Navy shipbuilding. Although the exact percentage that applied to ships is not known, the premium has been estimated at 30 percent for government procurement in general. [Perry, 1995] The requirements for 400+ SUPSHIP personnel at each major shipyard represent some portion of this cost and should be reviewed. The review should include examining the change order process, different progressing systems for the purpose of payments--including payments at major milestones--and the need for government hands-on quality testing. Greater reliance on the prime's internal system for progressing, and quality assurance should be examined. Wherever possible, hard copy CDRLs should be replaced by computer access to designated contractor data bases.

- Navy insistence on the contractor using the SWBS for progressing is counterproductive. Not only does it require time consuming and inaccurate conversions, it has been observed that some yards define work packages based on system rather than zone. This is in direct conflict with group technology shipbuilding. Product-orientation should be introduced during contract design and used for all planning, purchasing, progress reporting and cost collection throughout production, with the possible exception of some final testing. The MSSTDP includes a project, scheduled for 1996 completion, to provide the Navy with a product-oriented cost estimating system capable of supporting the PWBS developed by the GBS task.

- Rules for pricing and competition at the sub-contractor level should be revised. This is part of DOD's Acquisition Reform program and the details are beyond the scope of this study. At a minimum, however, use of partnering of prime and subcontractors and sole source subcontractors for fixed price contracts should be considered.

- Navy requirements which inhibit on-block/on-unit outfitting are in need of review. Brazed and welded pipe joints, long cable runs, second blast and prime, and requirements for extra paint coats are the most often mentioned. Painting and accuracy control appear to be the weakest areas with respect to cost and schedule among US Navy shipbuilders. A reevaluation of prohibitions on pipe couplings and cable splicing, and painting and blast requirements, along with studies of advanced painting systems, should be initiated. Accuracy

control systems should perhaps be required by contract and monitored for contractor compliance just as quality assurance systems are supposed to be now.

- Cyclicality of the market and small size of the industry has resulted in an acute supplier/sub-contractor problem. Every effort should be made to remove restrictions and accounting practices which inhibit suppliers from entering the U.S. naval ship market. Partnering arrangements should be encouraged and pricing and quality standards should be based on the market and ISO-9000 certification and compliance where possible.

There appear to be no significant barriers that would preclude the U.S. shipbuilding industry from re-entering the world market provided that foreign subsidies are eliminated as planned. In fact, in the absence of subsidies, the combination of relatively high U.S. shipbuilding technology (albeit not the very best) and lower compensation rates could give U.S. shipbuilders a comparative advantage. By adopting the kind of innovative manufacturing methods outlined in this chapter, U.S. shipyards could improve productivity and lower costs, and thereby enhance their competitive position. In the following chapter we will explore the broader economic consequences of doing this. On the other hand there is no compelling economic reason for U.S. shipbuilders to compete in the world market as long as the Navy work lasts. It is not clear that the U.S. shipbuilding industry can catch up in the areas of marketing and organization (soft technology) in time to become world class. It is incumbent on the government to remove bureaucratic and administrative barriers to the extent possible in order to give the U.S. yards a chance to become internationally competitive. The declining Navy backlog and each yard's own ability to compete will then result in their making the decision one way or another. It seems desirable from the industrial base standpoint for at least part of the industry to enter the world market for commercial ships. Even if this does not happen, the benefits to be derived from the government becoming a world class customer could significantly decrease DOD's acquisition and ownership costs.

REFERENCES

1. Advanced Marine Enterprises, *LX Preliminary Design (PD) Generic Build Strategy Study* (NAVSEA Tech. Note. No. 070-03R3-TN-0012), Department of the Navy, Naval Sea Systems Command, Arlington, VA, April 1994.

2. Bingaman, Jeff, Jacques Gansler, and Robert Kupperman, (Cochairs), *Integrating Commercial and Military Technologies for National Strength: An Agenda for Change*. Report of the CSIS Steering Committee on Security and Technology, The Center for Strategic and International Studies, Washington D.C., March 1991.

3. Borchers, K.H., G.L. Kraine, D.T. Thompson, and J.R. Wilkins, Jr., *Development of Producibility Evaluating Criteria*, NSRP Report 0342, September 1992.

4. Bosworth, Michael L. and Jeffrey J. Hough, *Improvements in Ship Affordability*, SNAME Centennial Meeting, New York City, September 14-19, 1993.

5. Bunch, Howard M., *Comparison of the Construction Planning and Manpower Schedules for Building the PD214 General Mobilization Ship in a U.S. Shipyard and in a Japanese Shipyard*, Maritime Administration, Washington D.C., July 1987.

6. Carpenter, LCDR John D., USN and LCDR Peter C. Finne, USN, "Navy Ship Procurement," *Naval Engineers Journal*, December 1972 (69-81)

7. Chirillo, L.D., and R.D. Chirillo, "The History of Modern Shipbuilding Methods: The U.S.-Japan Interchange," *Journal of Ship Production*, Vol. 1, No. 1, February 1985, pp. 1-6.

8. Chirillo, L.D., Comment on Lamb, T., A. Allan, J. Clark and G. R. Snaith, *A Review of Technology Development, Implementation, and Strategies for Further Improvement in U.S. Shipbuilding*, SNAME Annual Meeting, Washington, DC, October 4-7, 1995.

9. Christensen, Walter L. and Philip C. Koenig, "Standard Outfit Packaging Units in the LPD 17 Ship Design: A Production Impact Study," *Journal of Ship Production*, Vol. 11, No. 4, November 1995.

10. Clausing, Don, *Total Quality Development A Step-By-Step Guide to World Class Concurrent Engineering*, ASME Press: New York, 1994.

11. Collins, CAPT John T., "USS Spruance (DD 963) Class, Designed for Change—The Payoff is Now," *Naval Engineers Journal*, April, 1975.

12. Committee on U.S. Shipbuilding Technology, *Toward More Productive Naval Shipbuilding*, Marine Board. Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington D.C., 1984.

13. Daidola, John C., John Parente and William H. Robinson, *Hull Structural Concepts for Improved Producibility-Tankers*, Ship Structure Committee, U.S. Coast Guard, Washington, D.C., December 15, 1994.

14. Department of the Navy, "Total Quality Management (TQM) Awareness Seminar," 1 October 1989.

15. Ferreiro, Larrie D. and Mark H. Stonehouse, *A Comparative Study of U.S. and UK Frigate Design*, SNAME Annual Meeting, November 14, 1991.

16. Hammon, Colin and David Graham, *Disruption Costs in Navy Shipbuilding Programs*, Center for Naval Analyses, Alexandria, Virginia, Study Report CNS 1149/April 1980.

17. Horne, RADM R. B. Jr., *NAVSEA Ship Design, Acquisition and Construction Process Improvement Project: Workshop II*, Naval Sea Systems Command, 6-7 May 1991.

18. Hough, Jeffrey, ATC Program Manager (NAVSEA 03R3), *Affordability Through Commonality*, Presentation to IDA study team members, September 1995.

19. Huthwaite, Bart, *Strategic Design: A Guide to Managing Concurrent Engineering*, Institute for Competitive Design, 1994.

20. *Janes Fighting Ships*, Ninety-Eighth Edition, 1995-96, Janes Information Group Limited, Surrey UK, 1995.

21. Kaitz, E.M. and Associates, *The Capital Budgeting Policies of the U.S. Shipbuilding Industry: An Analysis of Defense Industry Behavior*, Office of Naval Research, October 1979.

22. Keane, R. G. Jr., B. F. Tibbitts, and T. A. Beyer, *From Concept to Commissioning: A Strategy for the 21st Century*, SNAME/ASNE Ship Design Symposium, February 1992.

23. Maritime Administration. *Outlook for the U.S. Shipbuilding and Repair Industry-1995*, U.S. Department of Transportation, Washington, DC. 1995

24. Nagel, Roger and Rick Dove, *21st Century Manufacturing Enterprise Strategy: An Industry Led View*, Vol. I and *21st Century Manufacturing Enterprise Strategy: Infrastructure*, Vol. II, Iacocca Institute, Lehigh University, Bethlehem, PA. 1991.

25. Perry, William J., *Acquisition Reform*, Secretary of Defense Memorandum, 15 March 1994.

26. Peters, Hans Jurgen, *The International Ocean Transport Industry in Crisis*, The World Bank, Working Paper WPS 1128, Washington, D.C., April 1993.

27. Rains, Dean A., *Naval Ship Affordability Studies*, Presentation to Institute for Defense Analyses, June 20, 1994.

28. Ranson, G.N, *Group Technology: A Foundation for Better Total Company Operation*, McGraw-Hill, London, 1972.

29. Rost, Ronald F. and Carla E. Tighe, *Shipyard Costs and Capabilities*, Center for Naval Analyses, CRM 92-13, May 1992.

30. Ryan, J. Christopher (Kit) and Otto P. Johns, *Improving the Ship Design, Acquisition and Construction Process*, Association of Scientists and Engineers 28th Annual Technical Symposium, 11 April 1991.

31. Spicknall, Mark H. and Michael Wade, *Reducing the Construction Contract Cycle for Naval Auxiliary Ships*, SNAME, NSRP Ship Production Symposium, September 2-4, 1992.

32. Storch, R. L., Appledore International Ltd. and Thomas Lamb, *Requirements and Assessments for Global Shipbuilding Competitiveness*, NSRP, Ship Production Committee Design/Production Integration Panel (SP-4), October 7, 1994.

33. Storch, R. L., John Clark, and Thomas Lamb, *Technology Survey of U.S. Shipyards-1994*, SNAME, Paper presented at the 1995 Ship Production Symposium, Seattle January 25-27, 1995.

34. Summers, Andrew B, Trip Report, Japanese Aegis Destroyer, Naval Sea Systems Command, NAVSEA 05D, March 18, 1993.

35. Tibbitts, B. F. and R.G. Keane, Jr., "The Warship Design Process: Making Design Everybody's Job," *Naval Engineers Journal*, May 1995.

36. Tibbitts, B. F., R. G. Keane, Jr., and R. J. Riggins, "Naval Ship Design: Evolution or Revolution?", *Naval Engineers Journal*, May 1988.

37. Tibbitts, B. F., R. G. Keane, Jr., P.M. Covitch and E. N. Comstock, *Naval Ship Design in the 21st Century,* SNAME Transactions. 1993.

38. Tibbitts, B. F. and R. G. Keane, Jr, *Shipbuilder Participation in Early Design Stages*, SEA 03D5 Slide Presentation, May 1994.

39. Wade, Michael and Zbigniew J. Karaszewski, "Infrastructure Study in Shipbuilding: A Systems Analysis of U.S. Commercial Shipbuilding Practices," *Journal of Ship Production*, Vol. 8, No. 2, May 1992, pp.-129.

40. Wilkins, James R. Jr., Perry Singh, and Todd Cary, *Generic Build Strategy-Preliminary Design Experience*, The Society of Naval Architects and Marine Engineers 1995 Ship Production Symposium, January 25-27, 1995.

41. Wilkins, James R. Jr., Gilbert L. Kraine, and Daniel H. Thompson, "Evaluating the Producibility of Ship Design Alternatives," *Journal of Ship Production*, Vol. 9, No. 3, August 1993, pp. 188-201.

This page intentionally left blank

IV. POTENTIAL FOR U.S. SHIPBUILDERS IN COMMERCIAL MARKETS

A. SCOPE AND METHODOLOGY

The President's Initiative with respect to the strengthening of U.S. private shipyards in the world commercial shipbuilding market [President, 1993] raises a variety of important economic, political and strategic questions. Among the more important questions with economic implications are the following:

1. After having abandoned the export market for commercial shipbuilding for 37 or more years, can American shipyards reenter a highly subsidized world market with technologically advanced rivals and attain an economically competitive position which can be sustained over time?[1]
2. Does the possibility of success imply the need for an active U.S. government industrial policy and subsidies to counter their widespread use by foreign nations?
3. Are the subsidies and capital funds that may be necessary an efficient usage of national resources? If so, should such support be extended to all existing shipyards or limited to a subset judged to be the most promising candidates?
4. Is this an industry in which a technologically advanced economy like the United States or Japan has a potential comparative advantage, either across the broad spectrum of ship types or in niche markets?
5. To what extent do the national security benefits of a domestic commercial shipbuilding capacity override the potentially lack of competitive viability?

Although the primary focus of this chapter is on the first two of these economic questions, the assessment casts some light on the last three as well.

---

1 The last commercial ship exported from the United States was in 1957 [Carson and Lamb, 1990]

1. Structure of the Analysis

Demand projections for shipyard new building over the next 10 and 15 years were obtained from existing literature. These forecasts we found to be highly uncertain, even from the consulting firms judged the best in the field. Indeed, the more qualified the forecaster, the more extensive the caveats accompanying their results. The difficulties are multifold, and will be discussed in greater detail throughout the chapter. Briefly they hinge on the difficulty of making demand forecasts for industries whose products are quite long-lived, demand for which is derived from underlying demand for transportation services provided by firms, many of which have limited ability to raise capital. Such industries are subject to great cyclicality and uncertainty. Currently, capacity in commercial shipbuilding is estimated to be well in excess of demand; about 20 percent by most estimates. Capacity has remained reasonably stable since 1980, with excess capacity fluctuating from 15 percent in 1985 to 45 percent in 1989 and back to about 20 percent currently. [Ocean Shipping Consultants, 1993]

There is extensive interest by U.S. shipbuilders in the commercial market. (See Table 33.) They see the commercial market as an important complement to their naval shipbuilding activity. It has been a popular belief that the building of commercial ships in a declining naval market might be useful in maintaining the U.S. industrial base in shipbuilding while at the same time providing a "learning environment" for the managers of U.S. naval shipyards. The nature of naval ship construction has been that of a market dominated by a monopsony (single) buyer (the U.S. Navy) while the suppliers are oligopoly (a few large) sellers. This is not a market fraught with incentives for innovation or competitive pricing. It is a "comfortable" market for those builders with enough business.

However, the naval shipbuilding business has begun to decline and will likely continue to do so over the next decade. Therefore, it is important to examine carefully the opportunities for U.S. shipbuilders in the world market. We have sought to study this market in all its dimensions to identify where there may be opportunities for U.S. builders. Commercial shipbuilding is only one of many ways to give limited support to our industrial base.

Table 33. Commercial Shipbuilding Plans of Major U.S. Shipyards

Shipbuilders	Naval Ships Orderbook	Commercial Considerations	Foreign Alliances
Bath Iron Works	DDG 51	Refrigerated Car Carrier	Kvaener Masa, Mitsui
Newport News	CVN SSN 688 SEALIFT (C)	Product Tanker (2+2)	IHI Plus
Ingalls	DDG-51 CG-47 LHD 1	VLCC, Cruise Ship, Mid-Size Tankers	
Avondale	T-AO LSD WAG B 20 MHC SEALIFT	Mid-Size Tankers	None
National Steel	AOE SEALIFT (C) SEALIFT	Cruise Ship Tankers	Kawasaki
McDermott Ship Building		Small Container Ships 1100 TEU (10 30)	

Commercial shipbuilding requires fewer workers of a skill composition less diverse than naval shipbuilding and outfitting. Consequently, commercial building is only a partial answer to the maintenance of our naval building capability. Capacity for commercial building is on the increase, with the Koreans leading the way. The Koreans appear dedicated to doubling their capacity by the turn of the century (see Table 34); a factor which is likely to apply downward pressure on commercial ship prices, particularly tankers and bulk carriers.

Table 34. World Shipbuilding Capacity (Millions of Deadweight Tons)

		2000	
Nation or Region	1994	Scenario I	Scenario II
Korean	5.0	9.5	11.0
Japan	9.0	7.5	9.0
Europe	4.0	4.5	4.5
Others	4.0	5.5	5.5
Total	22.0	27.0	30.0

For purposes of the study it is assumed that the numbers of ships of relevant interest demanded worldwide will provide a sufficient opportunity to U.S. shipyards to

enter the market. That is, it is assumed that demand will not be a limiting factor, but that costs, government subsidization policy and other circumstances will dictate outcomes.

With these limitations in mind, a notional U.S. shipyard was assumed to be in existence and to be capable of long-hulled ship production. We assumed, however, that the yard would need capital investments to adapt its plant and labor force to modern, technologically advanced methodology for commercial shipbuilding. The minimum typical capital needs of these types were identified, costed and annualized in order to estimate incremental annual amortization costs. Existing capital is assumed to be a sunk cost (completely amortized). Thus, the amortization costs we identify are incremental and relate to the modernization of the commercial operations of the shipyard only. An estimated rate of return on the capital borrowed was added to obtain an estimate of notional modernization economic capital costs. [Shipbuilders Council of America, 1994]

To estimate comparative current costs, the study team developed a detailed classification of labor, material, and overhead costs, along with factors relevant to the behavior of such costs. Owing to constraints on study resources, we adopted two simplifications: first, the cost categories were condensed into the three aggregate classes of labor, material and overhead costs, and second, only one ship type was studied in great detail, although some data are listed for smaller sizes of that same type. The motivations for these choices will be discussed in more detail below.

The next step in the methodology was to estimate the costs of labor, materials and overhead in the production of identical ships in Japan, Korea and West Germany. This list excluded important competitors in Europe and Asia, but study resource constraints, as well as data availability and comparability problems, made their exclusion necessary. Comparative capital and current costs comprise one side of the competition ledger. The other is expected sales prices for future ships. This brings into play two important considerations: (1) the historical and prospective price stability of the shipbuilding industry, and (2) the thorny question of government subsidies to fund the differences between prices and costs.

2. Choosing a Notional Ship Type

The initial effort to construct and cost a notional shipyard will be confined to study of the production of a product tanker in the 50,000 to 60,000 deadweight ton (dwt) class. The reasons for this choice are listed below:

1. The tanker (crude and product) dominates the projected world newbuilding demand. New orders for all commercial ships (see Table 35) reached a level of more than 26 million gross tons (mgt) in 1994, with 45 percent of the orders going to Japan and another 22 percent going to Korea, while Europe held 13 percent of the world market for new orders. Completions of new ships reached more than 17 million gross tons (mgt) in 1994, with almost 70 percent of the deliveries from Japan and Korea. The world wide order book for commercial ships was estimated at more than 45 mgt at the end of 1994. Japan holds 32 percent and Korea 27 percent of the current world order book for newbuilding. The Europeans still have 16 percent of the backlog. The order books have been growing for Poland, China, and Taiwan, especially for medium size tankers.

2. The product tanker, designed to transport refined petroleum products such as gasoline, gas oil, jet fuel, kerosene and naphtha, is well-suited to U.S. ship production techniques. The product tanker often carries a variety of these products simultaneously, so that it is equipped with a large number of cargo tanks and fitted with segregated cargo equipment. Anti-corrosion and anti-pollution coatings of some sophistication are used to line the tanks. These tankers are, therefore, a technologically more sophisticated product with more promise for exploiting U.S. technical achievement than crude petroleum tankers, in whose production Japan and Korea have long experience and have moved far down the learning curve.

3. Within the tanker complex, demand for product tankers is projected to grow more rapidly over the next 10 to 15 years than demand for crude tankers. Ocean Shipping Consultants (OSC) has projected world oil demand by region for 1994 through 2004 with a breakdown between crude and product shipments. [Ocean Shipping Consultants, 1993]. It is expected that over this period a significant expansion in oil imports to North America will occur, with product imports expected to increase sharply as refinery capacity is moved offshore. Crude shipments to Europe are expected to decline over this period by about 12 percent but product imports are projected to rise by about the same percentage. The forecast for Japan repeats the same pattern: crude imports decline by 10 percent while product shipments rise by 93 percent. Only in Southeast Asia is the forecast for crude shipments to expand by a higher percentage than product shipments. For the world as a whole, oil consumption is projected to grow about 50 percent by the end of the century and 15 percent over the following 5 years. Demand for refined products is expected to grow by 60 percent over the whole period.

Table 35. World Shipbuilding Market

	Year	Korea		Japan		Western Europe		Others		World	
		GT	Share (%)	GT	Share (%)	GT	Share (%	GT	Share (%)	GT	Share (%)
N	1980	1,706	9	9,997	53	4,472	24	2,794	15	18,969	100
e	1981	1,372	9	8,303	49	4,130	24	3,072	18	16,877	100
w	1982	1,075	10	5,570	50	2,096	19	2,446	22	11,187	100
	1983	3,733	19	10,982	57	2,069	11	2,639	14	19,423	100
O	1984	2,289	15	8,844	57	2,095	13	2,353	15	15,581	100
r	1985	1,339	10	6,358	49	2,040	16	3,169	25	12,906	100
d	1986	3,056	24	5,518	44	1,667	13	2,423	19	12,664	100
e	1987	4,106	30	4,771	35	2,573	19	2,264	16	13,768	100
r	1988	2,755	23	4,631	39	2,000	17	2,455	21	11,841	100
s	1989	3,223	17	9,695	50	3,202	17	3,186	17	19,306	100
	1990	5,737	24	11,143	46	4,231	18	2,954	12	24,067	100
	1991	5,011	25	8,120	41	3,094	15	3,769	19	19,994	100
	1992	2,213	17	5,248	40	2,521	19	3,016	23	12,995	100
	1993	8,888	38	7,599	32	4,342	18	2,710	12	23,539	100
	1994	5,733	22	11,940	46	3,526	13	4,941	19	26,`40	100
C	1980	522	4	6,094	47	2,989	23	3,496	27	12,101	100
o	1981	929	5	8,400	50	4,131	24	3,472	21	16,932	100
m	1982	1,401	8	8,163	49	3,864	23	3,392	20	16,820	100
p	1983	1,539	10	6,670	42	4,224	27	3,478	22	15,911	100
l	1984	1,473	8	9,711	53	3,499	19	3,651	20	18,334	100
e	1985	2,620	14	9,503	52	2,958	16	3,076	17	18,157	100
t	1986	3,642	22	8,176	49	2,059	12	2,966	18	16,845	100
i	1987	2,091	17	5,708	47	1,977	16	2,483	20	12,259	100
o	1988	3,174	30	4,040	37	1,715	16	1,980	18	10,909	100
n	1989	3,102	23	5,365	41	1,988	15	2,781	21	13,236	100
	1990	3,460	22	6,824	43	2,849	18	2,752	17	15,885	100
	1991	3,497	22	7,283	45	2,890	18	2,425	15	16,095	100
	1992	4,502	25	7,569	42	3,298	18	2,829	16	18,198	100
	1993	4,467	22	9,086	45	3,815	19	2,657	13	20,025	100
	1994	3,975	22	8,387	47	2,558	14	2,988	17	17,908	100
O	1980	2,489	7	13,072	38	9,741	28	9,326	27	34,628	100
r	1981	2,977	8	12,655	36	9,803	28	9,876	28	35,311	100
d	1982	2,551	9	10,067	35	8,136	28	8,418	29	29,172	100
e	1983	4,618	14	14,027	43	5,797	18	8,177	25	32,619	100
r	1984	5,798	19	13,072	43	4,642	15	7,176	23	30,688	100
b	1985	4,667	18	9,729	38	3,984	15	7,482	29	25,862	100
o	1986	4,223	20	6,568	31	3,606	17	6,967	33	21,364	100
o	1987	6,021	27	5,038	22	4,510	20	6,973	31	22,542	100
k	1988	5,865	24	5,959	24	5,164	21	7,565	31	24,553	100
s	1989	6,027	19	10,278	33	6,498	21	8,252	27	31,055	100
	1990	8,521	21	14,651	37	8,560	22	8,057	20	39,789	100
	1991	9,433	22	15,719	36	8,615	20	9,397	22	43,164	100
	1992	7,029	19	13,249	35	7,550	20	9,505	25	37,333	100
	1993	10,905	28	11,456	29	7,960	20	8,921	23	37,242	100
	1994	12,237	27	14,658	32	7,276	16	11,621	25	45,792	100

Source: Lloyd's

The world ship market in which the product tanker finds itself has often been predicted to be a booming market during the mid to late 1990s. The assumption is that the crude tanker market which consists of a large percentage of ultra-large crude carriers (ULCCs) and very large crude carriers (VLCCs) built in the big surge of the early 1970s is growing old and will need replacement in the 1990s. This may not be the case because of several factors. Tankers are projected to have a service life of 20 years, but if the market demand is high, newbuilding will be expensive and the economic value of old tankers may be such that their lives will be extended when new tankers pose risky investments. The predicted newbuilding boom of the 1990s has not yet appeared. Additionally, as we pointed out earlier, the demand for crude carriers is shifting somewhat toward product carriers and thereby delaying the replacement boom in VLCCs. Prices were high in 1993 for newly built ships of most kinds but prices have declined in 1994 and held steady in 1995. New VLCCs are currently selling for $80-90 million, down 20 percent from their 1993 peak. There are currently 52 VLCCs on order. More than 300 small tankers and bulkers are on order from the Handymax up through the Handy. The specialized market, more suitable for U.S. shipbuilders, shows more than 120 product tankers and more than 250 container ships on order.

Another potential market for U.S. shipbuilders is the liquid natural gas (LNG) carrier of which there are 28 on order, priced between $200 million and $300 million each. Bulk carriers on order number more than 400. The order book for all types of tankers and bulk carriers totaled almost 30 million dead weight tons at the end of 1994. The total orderbook at the end of 1994 was more than 60 million dead weight tons. (All figures used here are from various publications of Clarkson Research Studies, Ltd., London.)

Freight rates for VLCC crude carriers have remained too low into the mid-1990s to pay for the cost of the ship. Torben Andersen, Executive Vice President of Odense Steel shipyard, pointed out that the cost of operating a VLCC is currently (April 1995) about $40,000 per day, while the freight rates are running about $10,000-$12,000 per day. This led A.P. Moller of Maerch Shipping to say that he is glad Maersk has only 10 VLCCs operating since he is losing $25,000 per day on each one.

4. Projections of demand for product tankers is further complicated by the flexibility of usage among crude and product tankers. Consequently, in periods of high demand for product shipments, it is often possible to substitute crude carrier capacity, and vice versa. Hence, future demand and

usage of product tankers may not reflect exactly demand factors for petroleum products.

In 1990, the worldwide product tanker fleet totaled about 40.3 million dwt, or about 17 percent of the total tanker deadweight tonnage. However, in the period 1980 to 1990 the most notable feature of the structure of this total fleet was the decline of the VLCC/ULCC fleet. Vessels over 150,000 dwt suffered a reduction of 42 percent in deadweight tonnage, whereas vessels in the 10,000 to 60,000 dwt classes, most of which consist of product tankers, actually rose by 0.5 percent over the period [Ocean Shipping Consultants, 1993]. This product tanker weight class, therefore, is the most rapidly rising portion of the tanker fleet.

Moreover, from the late 1970s to 1990 deadweight tonnage of the worldwide product tanker fleet rose over 50 percent although smaller product tankers showed marked declines. For example, product tankers in the 10,000 to 16,000 dwt class declined from 21 percent to only 5 percent of product tanker total and those in the 16,000 to 25,000 class fell by more than half to 13 percent. On the other hand, the 25,000 to 40,000 dwt class rose 10 percent to comprise about 47 percent of the product tanker fleet deadweight tonnage. Also, vessels in the 50,000 dwt and larger classes rose to comprise 25 percent of the product tanker fleet deadweight tonnage. This coincides with a change in the demand for product tanker usage that began in the 1980s: prior to that time, product tanker demand was characterized by the use of smaller sized vessels on short-haul trades. In recent years, however, the rapid expansion in refinery capacity over the world (and especially in Kuwait and Saudi Arabia) has led to the dominant share of such demand arising in the long-haul sector with the larger size tanker benefiting disproportionately.

In 1990, 56.5 percent of the existing product tanker fleet was between 25,000 and 50,000 dwt range. [Ocean Shipping Consultants, 1993] Our choice of the 55,000 dwt class for the preliminary analysis, therefore, is consistent with the current structure of the tanker fleet.

Future demand for product tankers will also be affected by U.S. regulations concerning Segregated Ballast Tanks, which will enhance future demand for new product tankers. The regulations require all product tankers built before 1976 to be equipped with clean ballast tanks in order to trade in U.S. waters. Since these vessels were typically in the 30,000 dwt to 35,000 dwt classes, such retrofitting will reduce their cubic capacity by about 30 percent, making them uneconomical for shipping. Their replacement will enhance newbuilding. [Ocean Shipping Consultants, 1993]

The Oil Pollution Act of 1990 requires all single-hulled, double-sided, or double-bottomed tankers in U.S. waters to be phased out in favor of double-hulled vessels (i.e., both double-bottomed and double-sided), starting in 1995. This will give a further boost to the product tanker market over the next 15 years.

OSC projects total product tanker newbuilding in the decade of the 1990s at 21.9 million dwt, with 4.4 million dwt or 20 percent in the 40,000 to 60,000 deadweight class, 11.9 million or 54 percent in the less than 40,000 dwt class, and 26 percent or 5.6 million dwt over 60,000 dwt. [Ocean Shipping Consultants, 1993] The Shipbuilders Council of America (SCA) projects a product tanker fleet size between 51 million and 60 million dwt in 2000, for a net rise of 11 million to 20 million dwt, or 27.5 to 50 percent over 1990 levels. [Shipbuilders Council of America, 1990] The outlook for the next 10 to 15 years, therefore, is an optimistic one for product tankers, notably in the smaller classes up to 50,000 dwt. It provides a promising niche, therefore, for U.S. shipbuilders seeking to reenter the commercial shipbuilding market.

Table 36 forecasts tanker demand by size of crude and product carriers, by type of ship. The basic assumption is for a growth in demand for haulage of both crude oil and refined oil products. Our own emphasis leans more toward a growth in the haulage of products, with less analysis on movement of crude oil.

Table 36. Summary: Forecast Tanker Demand by Type/Size to 2005 (Billion Tonne-Miles)

Ship Type and Site	1991	2000	2005	Percent Rise
Crude Carrier				
10/60,000 dwt	269	291	326	21
60/100,000 dwt	842	903	941	12
100/150,000 dwt	1078	1083	1066	-1
150/200,000 dwt	471	421	435	-8
200/300,000 dwt	2826	2997	3126	11
3000,000 + dwt	1030	1201	1298	26
Product Tanker				
10/25,000 dwt	424	577	594	40
25/40,000 dwt	440	682	735	67
40/60,000 dwt	505	866	905	79
60,000 + dwt	260	499	594	128

Source: Ocean Shipping Consultants Ltd.

A breakdown of the tanker and bulker fleet on order is shown graphically in Figure 20. Table 37 provides another interesting perspective on forecasts of tanker demand over the next decade. The forecast is presented as demand for tanker usage in billions of ton miles and is based on a thorough study of such demand by Ocean Shipping Consultants. Case 1 is based on an extrapolation of current demand, case 2 is drawn from a slightly more optimistic assumption based on a reduction in North Sea crude production, while case 3 is based on pessimistic assumptions about world crude and refined product usage.

Finally, a review of the MARITECH awards for tanker research in FY 1994 reveals that U.S. consortia formed to perform such research have emphasized a concern with product tankers in the 40,000 dwt category. Of the 8 awards in the tanker category, 6 are specifically for product tankers, and 5 of those 6 concentrate on 40,000 dwt vessels. [Shipbuilders Council of America, 1994] This is also a solid indication that vessels of this type and size are viewed by U.S. shipbuilders as a promising niche market.

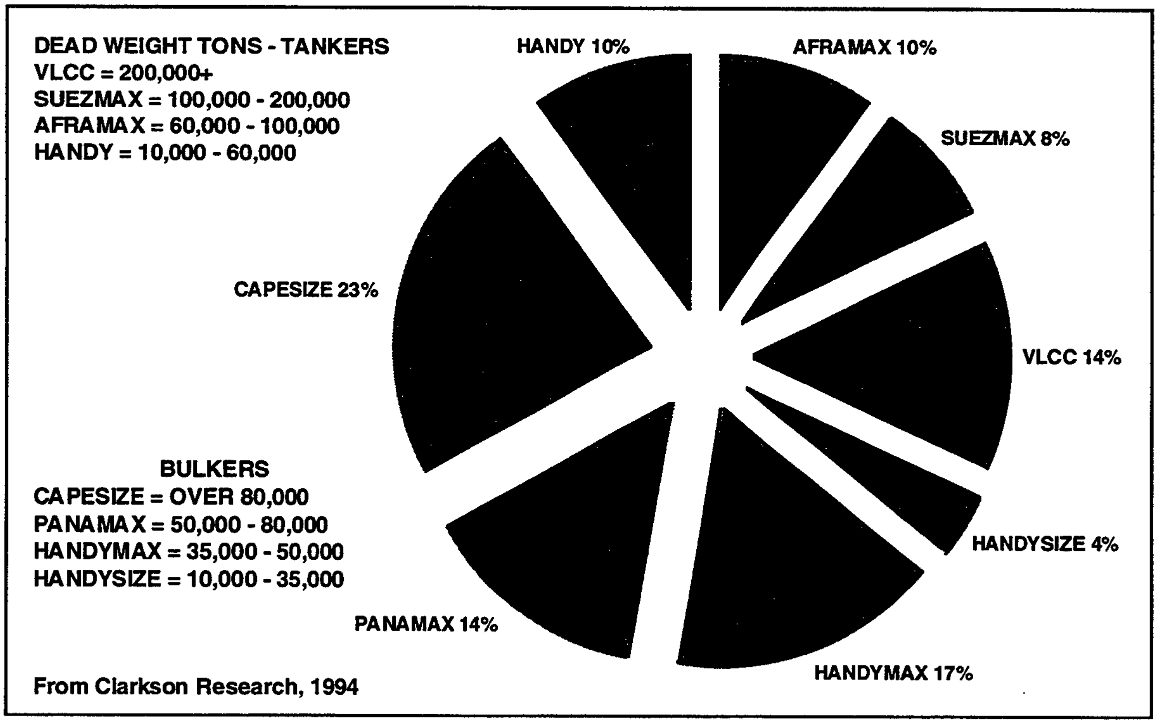


Figure 20. Tankers and Bulkers, On Order, June 1994
Percentage of Each Type

Table 37. Summary: Forecast Tanker Demand to 2005
(Billion Tonne-Miles)

Projection	Crude	Products	Total	Index
Case 1				
1991	6561	1630	8146	100
1995	6703	2159	8862	109
2000	6895	2624	9519	117
2005	7192	2827	10019	123
Case 2				
2000	7252	2884	10136	124
2005	7736	3365	11101	136
Case 3				
2000	6353	1737	8090	99
2005	6262	1493	7755	95

Source: Ocean Shipping Consultants Ltd.

B. CAPITAL COSTS

1. Capability for Commercial Shipbuilding

Most of the new capital needs for a shipyard preparing to enter the international commercial new shipbuilding market arise from the need to:

- Develop a library of ship designs which are standardized for efficient production yet flexible enough to permit customization for customers' demands; U.S. shipbuilders in the past have been accustomed to build single ships or ship classes to customer-supplied designs.
- Produce such ships in series and by modern modular techniques, which require preassembly of blocks of components using computerized software and robotics, and sufficient lifting capacity to permit heavy modules (up to 200 metric tons) to be emplaced in hulls.
- Computerize and robotize production and assembly facilities to accommodate series production of commercial ships, especially ships requiring more advanced and complicated construction in whose production U.S. shipbuilders are expected to find a comparative advantage.

In Table 38 the physical facilities necessary for a modern notional shipyard fully capable of producing product tankers of the 40,000 and 55,000 dwt size are listed. In most instances, we judge that U.S. shipyards will have to undergo substantial incremental

capital costs to modernize the facilities to become competitive in the product tanker markets.

In addition to these costs, which are largely for structures and equipment, expenditures will also be required for less tangible items. Alterations in the layouts of the yards to accommodate novel process flows will have to be financed. Development or franchise of a library of designs which can be readily customized to customer needs will require an initial expenditure of capital. Human capital costs in the form of retraining existing or new laborers in altered techniques must also be budgeted and amortized over time.

Table 38. Capital Facilities Necessary for Notional Shipyard to Produce 40,000 and 55,000 dwt Product Tankers

1.	Building position with minimum length of 200 meters for 40,000 dwt vessel and 220 meters for 55,000 dwt vessel.
2.	Gantry crane spanning building position and work platen with lifting capacity of at least 200 long tons.
3.	Machine shop.
4.	Steel fabrication facility for the fabrication of structural steel; plate preparation; computerized burning machines; cutting, grinding, shearing, forming, milling and sawing, preferably connected to CAD system.
5.	Pipe fabrication, with mechanized gear and subassembly tools.
6.	Sheet metal facility.
7.	Module outfitting facility for assembling and installing modules, most under cover, with hydraulic equipment for lifting, transportation equipment for moving, equipment to join modules and interconnect systems.
8.	Electrical shop.
9.	Plating shop.
10.	Warehousing area.
11.	Foundry.
12.	Engineering, design and R & D facilities.
13.	Computer centers, including scheduling capability.
14.	Testing facilities.

U.S. shipbuilders have made substantial investments in capital facilities over the last 10 years, largely to "improve efficiency in the Navy's construction, repair and overhaul projects, which were considered the most consistent and stable element in the industry's projected market." [Maritime Administration, 1994] The record is given in Table 39.

Much of this investment was financed directly or indirectly by Navy contracts, of course, but since it included building basins, floating dry-docks, cranes, automated equipment and mechanized modular technique equipment, some dual capability for commercial shipbuilding was no doubt obtained.

To derive accurate estimates of the additional capital costs needed to modernize an existing Navy-oriented shipyard in order to compete in the international product tanker market would require extensive research well beyond the scope of this study. Consequently, we have based our estimated on a brief overview of capital costs in the industry and consultation with interested parties. Using this approach we have arrived at a conservative estimate of at least $75 million for a shipyard of the type envisioned for product tanker construction. No doubt some portion of this expenditure could be used in the construction of other types of vessels, but to be conservative we have assumed that the amortization costs must be charged wholly to annual tanker production.

Table 39. Capital Investments in the U.S. Shipbuilding and Repair Industry, 1985-93 (Millions of Current Dollars)

Year	Actual Investment
1985	262.0
1986	225.0
1987	150.0
1988	145.0
1989	196.0
1990	210.0
1991	228.0
1992	215.0
1993	161.0

Source: [Maritime Administration, 1994].

Finally, given the extremely cyclical nature of the industry and the uncertain state of demand for even intermediate periods in the future, it would not be prudent to depreciate the capital over a period longer than 10 years. Therefore, as an initial estimate of incremental capital costs for the production of 40,000 to 55,000 dwt product tankers, we estimate an annual charge of $7.5 million. This is in addition to existing capital costs that are presently included in annual overhead, although we assume these are minimal because most of the shipyard's equipment has been depreciated fully.

Annual interest charges on such capital improvements must also be calculated over the 10-year amortization period. Much of the good research that has been done in this area concerns the availability of capital for ship owners and shipping companies, whose risk situations are allied to but somewhat different in nature from those of ship producers (see, for example, [Goldrein, 1993] and [Lloyd's Shipping Economist, 1993]). Shipping companies are frequently partnerships or family-owned proprietorships, with few assets other than ships, and rightfully protective of information concerning their financial conditions. Long term capital, therefore, is difficult to access, and is frequently provided at subsidized rates by foreign governments or government agencies eager to encourage their domestic shipbuilding industries.

The pass-through effects of these capital restraints on ship owners—as well as relatively high-cost borrowing to finance ship operating expenses—are important in understanding the risk profile of the shipbuilding industry. Its constituent companies are almost invariably corporations, frequently subsidiaries of conglomerates, with differential capital availabilities. The stronger may finance in large part or wholly out of retained earnings, in which case costs are imputed rather than monetary, or issue debt with a credit rating based on extensive corporate or conglomerate resources. On the other hand, weaker companies will face less receptive security markets, with little chance of issuing equity and whose bonds may fall in the "junk bond" category.

The study team used Tenneco Corporation's current capital cost as a lower bound. On August 19, 1994 its 7 $^{7}/_{8}$ bonds due in 2002 were selling at 99$^{1}/_{2}$ for a current yield of about 8 percent. As a conservative estimate it was assumed that the notional shipyard would have to pay 10 percent per annum on unamortized debt of 10 years maturity. The annual payment will range from $750,000 to $7.5 million in our estimate of incremental modernization debt for an average undiscounted annual payment of $4.125 million. Adding this to the annual amortization payment we obtain an average annual capital carrying cost of $11.625 million for the estimated incremental modernization capital over a 10 year period.

In the case of shipyards where space is constrained, a larger investments will be needed to transition to commercial building. Building new commercial-chip construction facilities is likely to necessitate investments of several hundred million dollars.

Table 40 characterizes the principal differences between naval and commercial building. The differences in steel handling, outfitting and the size of the work force are important differences in the two kinds of shipbuilding.

Table 40. The Nature of Navy vs. Commercial Ships

Characteristic	Navy Combatant Ships	Commercial Ships
Payload	High Technology, High Value Weapon Systems & Accommodations for Warfighting Crew of 200-400	Medium to Low Value Cargo & Operating Crew of 14-26
Speed	30 - 35 Knots	14 - 24 Knots
Displacement	3,000 - 10,000 Tons	25,000 - 500,000 Tons
Structure	1,000 - 4,000 Tons High Strength Steel, Aluminum, Composites	8,000 - 50,000 Tons Low Strength Steel
Propulsion Systems	Gas Turbines: 50,000 - 100,000 HP	Low Speed Diesels: 15,000 - 30,000 HP
Stealth	Extensive Noise Reduction Extensive Radar Signature Reduction	Not Applicable
Survivability	Redundant Systems Everywhere Extensive Fire Fighting Extensive Shock Hardening	Meets USCG Requirements
Arrangements	Every Area of Ship Densely Packed with Equipment, Cables, Pipes, Ventilation	Machinery Space Relatively Uncongested, Balance of Ship is Large Empty Cargo Space
Life Expectancy	30 - 40 Years	15 - 30 Years
Shipbuilding Facility	Low Volume Steel Capacity Small Building Berths Highly Integrated Outfitting Shops	High Volume Steel Capacity Large Building Berths Limited Outfitting Shops
Shipyard Employment at 2 Ships/Year	6,000 - 8,000	800 - 1,000

Source: Bath Iron Works, Corporate Presentation, November 1994.

2. Capability for Building Product Tankers

Were we able to analyze the current costs of production and the important factors determining them for our chosen product tanker type in detail, the framework presented in Table 41 would be adopted.

Most of the data available on costs is aggregated at the three-category level of labor, materials and overhead. Interviews with knowledgeable persons in shipyards and elsewhere have yielded some more detailed information, and where appropriate we have

used or adapted it. Nonetheless, by and large, it is necessary by virtue of data limitations to remain at the aggregate level.

Table 41. A Detailed Cost Framework for Analysis of the Current Costs of the Notional Ship and Shipyard

Labor Inputs	Materials Inputs	General Expense	Corporate Overhead	Ancillary Expense
Categories: 1. Hull 2. Electrical 3. Paint 4. Sheet Metal/ Joiner/ Insulation 5. Program Management and Quality Control 6. Other Determinants of Cost: 1. Labor hours 2. Money wage rate 3. Fringe benefits 4. Labor overhead	Steel Main engine Other materials and components	Detail design Quality control inspection Survey fees Dry docking Material control Risk insurance Miscellaneous production services	Sales expenses Administrative and management costs Depreciation	Construction time Vessel design Quality of specifications Number of identical ships ordered Owner's surveillance activity Owner-specified regulatory standards

Source: Adapted from [Lansburg et al, 1988].

C. AGGREGATE COST ANALYSIS OF A 54,000 DWT PRODUCT TANKER

In 1990 the Center for Naval Analyses (CNA) conducted a cost study for a 54,000-dwt, double-hulled, clean product tanker built to international standards. Table 42 divides the estimated cost for this tanker into labor, materials and overhead expenditures, and considers the cost of the eighth ship in a series for Japan, Korea, Germany and the United States, as well as a single-ship cost for the last two building nations. Costs are stated in millions of 1990 dollars and in percent-of-total cost magnitudes. In the last row the annual incremental capital costs per ship estimated in Section A have been added to the CNA estimates without deflation to 1990 prices. By including only one year's

incremental per ship capital costs, we have assumed implicitly that construction of such tankers will require no more than one year.

Table 42. Estimated Costs for a Standard 54,000 dwt Product Tanker Built for the World Market (Millions of 1990 Dollars)

Type Expenditure	Japan	Korea	Germany		United States	
	Series	Series	Single	Series	Single	Series
Labor	6 (12.8%)	6 (13.0%)	20 (27.0%)	14 (25.0%)	18 (25.7%)	12 (22.2%)
Material	28 (59.6)	26 (56.5)	31 (41.9)	26 (46.4)	33 (47.1)	29 (53.7)
Overhead	13 (27.6)	14 (30.5)	23 (31.1)	16 (28.6)	19 (27.2)	13 (24.1)
Total	47 (100%)	46 (100%)	74 (100%)	56 (100%)	70 (100%)	54 (100%)

* Single refers to production cost of a single ship, series denotes the cost of producing the eighth ship in a series.
** Added by present study from estimates in Section A.
Source: [Rost and Tighe, 1992].

1. U.S. Notional Shipyard and Foreign Yards

Clearly, on the basis of these cost estimates, unless the United States can produce this product tanker in series it cannot be competitive with Japan or Korea, which typically produce multiship series. Costs of a U.S. single ship are estimated to be about 50 percent above Japanese and Korean series costs. Labor cost differentials in these comparisons are the major hurdle for U.S. shipbuilders to overcome with current labor costs about two to three times the Japanese and Korean per ship levels. Note that these are labor costs per ship, not per hour. Japanese labor compensation rates are currently well above U.S. rates. Korea still has some advantage in hourly labor costs, although this differential is falling rather quickly over time.

2. Productivity and Labor Costs

The labor costs on series production are assumed to include an 88-percent learning curve for all four nations. Even when series production is considered, U.S. labor costs are higher than those for the two Asian competitors. Several cautions regarding the comparability of these data are relevant: in Japan, and possibly in Korea, shipyards employ more subcontracted components, so that what are labor costs to U.S. shipyards

may be hidden in materials costs in the Japanese and Korean figures. Also, foreign labor costs are translated into U.S. dollars at volatile foreign exchange rates, except in the case of the Korean Won, which is tied to the U.S. dollar. Legal and contractual fringe benefits also vary greatly among nations and may be included in wage costs or overhead depending on a nation's particular accounting practice. Even after discounting for these observations, however, U.S. per-ship labor costs and labor productivities place it at a substantial disadvantage in this area. Note, however, in both single-ship and series production, U.S. shipyard have a slight competitive advantage over German shipyards.

As shown Table 43 the United States has lower wages than the other shipbuilding countries, except for South Korea and Taiwan, but our concern is with labor cost per ship. This means the problem is not only wage cost per hour but the number of labor hours it takes to produce a ship as well. The Japanese are producing VLCCs using about 400,000 labor hours per ship, while the Koreans are using on the order of 600,000 labor hours. Even with this difference the Koreans have the advantage since their wage rate is only about half the Japanese rate. The Koreans also have an advantage in the price of their materials such as steel. With a wage rate on the order of $20.00 per hour, U.S. shipyards are competitive around the world, except for Korea and Taiwan. Nevertheless, productivity or value added per labor hour in physical output can approach that of Japan only in a series production of 8 or more ships.

Table 43. Productivity and Hourly Labor Compensation in U.S. and Competitors' Shipyards, 54,000 dwt Product Tanker

Measure	Series				Single	
	Japan	Korea	Germany	U.S.	Germany	U.S.
Productivity (Labor-Days per Ship)	45,000	99,000	65,000	100,000	96,000	146,000
Hourly Compensation (1990 Dollars)	16.00 (17.74)	7.80 (7.31)	26.50 (24.75)	15.60 (16.65)		

* Hourly Compensation as defined by the U. S. Bureau of Labor Statistics includes pay for time worked, other direct pay, employer expenditures for legally required insurance programs and contractual and private benefit plans, and any other labor taxes.

** Labor-Days/Ship are the number of direct labor-hours needed to build the ship from contract date to date of delivery.

Source: [Rost and Tighe, 1992]. Hourly Compensation rates in parentheses are 1991 estimates in 1991 dollars from [Shipbuilders Council of America, 1994].

Material costs for series production are seen to be similar across the four competitor nations. Shipbuilders worldwide now buy materials and components in global

markets, and hence cost differences tend to be small. Given that foreign costs have been converted to dollars based on frequently volatile foreign exchange rates, the differences easily fall within the margins for error.[2]

Overhead costs, of course, vary with the numbers of ships built. For series production they too are quite close among the countries studied, with Germany showing some disadvantage. However, it can be misleading to ignore what appear to be small cost differences, because profit margins also can be 5 to 10 percent of costs, or even less. Hence, a 3 percent total cost difference might translate into a 30 to 60 percent profit differential. These factors make it difficult to assess the importance of cost differences, especially among nations whose diverse currency translations, subsidy procedures and accounting practices make it difficult to develop comparable cost estimates.

Although U.S. shipbuilders appear to have a cost advantage over German shipyards for single-ship production, the U.S. yards are clearly not competitive with Japanese and Korean shipbuilders producing in series. Even when ships are assumed to be produced in series of eight, U. S. production costs are 15 percent above those of Japanese yards and 17 percent above those of Korean yards if incremental investment costs are excluded, and 18 to 20 percent above if such costs are included.

3. Further Examination of Productivity and Its Measures

a. Overview

A recent study has shown that significant differences exist in the physical output per labor hour (productivity) between shipbuilding in the United States, Japan and Germany. Work by A & P Appledore [1995] shows differences so large—U.S.: 150-200 labor hours per compensated gross ton (CGT), Japan: 17-22 labor hours per CGT, and Germany: 50-100 labor hours per CGT—as to warrant investigation into why such variations exist. A more detailed study comparing the technology used by U.S. and

---

2 Korea may still be an exception to this discussion. A large part (about 30 percent) of the Korea costs originate from local production for domestic yards. Example; cables, pipe, fittings, moorings, welding materials. World market prices and production costs of larger cargo ships, prepared by Burmeister and Wain for the Shipbuilders Council of America, 1989. This study looks at the future prospects for U.S. shipbuilding to 1993. B&W estimate that Korean costs of materials is 20 percent below Europe. Source: [Burmeister and Wain, 1989].

foreign shipbuilders provides some clues to the observed productivity differences [Storch et al, 1995].

Storch's study provides indications that both U.S. naval shipbuilders and foreign commercial builders have improved their technology bases over the past 34 years. Detailed comparisons indicate, however, that when the data are averaged and aggregated, U.S. yards are still not competitive with foreign yards. Relatively speaking, U.S. yards achieved a "score" of 3.4 as compared with a 4.0 for foreign yards. U.S. yards are particularly lacking in their organization of work. The U.S. yards also showed up poorly in contract scheduling, steelwork production scheduling, design for production and production engineering.

Poor organization of work and production scheduling are especially undesirable attributes for commercial shipbuilding, where close attention to work organization and scheduling is required for on time production and delivery. The most productive commercial yards are characterized by large building docks, extensive early outfitting, protection against the weather, heavy lift crane capability, widespread application of automation and computer-aided materiel control as well as quality control. Unfortunately, the comparisons are made in terms of CGT. This measure is only applicable to commercial ships. There are no well-defined coefficients for measuring relative productivity among builders of naval ships, nor is there a method for comparing naval shipyard productivity with commercial shipyard productivity.

In addition to the wage rates discussed previously, Table 43 above shows average productivity factors for the various nations (hours of direct labor per ship).[3] For series production hourly compensation for Japanese and U.S. shipyards was about the same in 1990, but Japanese productivity was more than twice as high. In large part, this is due to Japanese shipbuilders' exploitation of robotic, modular construction and just-in-time inventory techniques. This confirms the point that substantial investment in capital and

3 It should be noted that a good deal of suspicion is warranted for "hourly compensation costs" that are widely given in the literature. In U.S. statistical practice these include only legally mandated fringe benefits, such as Social Security and workers compensation levies on management. Such contractual obligations as medical and retirement benefits are frequently put in the firm's overhead costs. Hence, comparisons of "labor costs" may be grossly incomparable and must be researched extensively before they are reliable. We have found quoted labor costs for U. S. shipbuilding to be suspiciously low, and this has been confirmed in our interviews in the field.

software development will be required for a United States shipyard to become fully competitive with a Japanese yard, as discussed in Section A.

In the case of Korea, the labor advantage arose almost entirely from the low hourly compensation paid by the yards. Productivity in Korea is similar to that in U.S. shipyards. Therefore U.S. hopes for becoming competitive will depend on the ability of U.S. yards to invest in and exploit superior technology. Because Korean shipyards are new and feature modern technology, much of it government-financed, their intensive use of labor must be due to its low price. If Korean wages rise in the future, it seems likely that they would begin to substitute capital for labor so as reduce labor-hours per ship.

Some consolation may be found in the comparison with German shipbuilding costs. Although German labor-hours were only 65 percent of U.S., its hourly compensation was 70 percent higher.[4] As indicated in Tables IV-9 and IV-10 shown earlier, these offsetting factors yielded series costs that were only 3.7 percent higher in German yards than in U.S. yards. This is well within the limits of error of estimation, and it is prudent to treat U.S. and German costs in producing this 54,000 dwt product tanker in series as essentially equal. Although Japanese shipyards subcontract for more materials and components than others, vertical integration may yield lower costs. We can assume that Japanese materials costs are about on a par with those in other countries. Finally, the 95-percent learning curve in materials usage was adopted by CNA to proxy the economies achieved as a result of production experience with familiar contractors.

In U.S. shipyards, overhead is typically computed as a percentage of direct labor costs; the SCA has suggested a factor of 140 percent be applied to labor costs to account for overhead representative. European shipyard practice is uncertain, as are Japanese and Korean overhead policies. The estimates given, therefore, are uncertain.

Burmeister and Wain [1989] estimated that production costs (labor, materials, capacity) were as much as 95 percent higher in Western Europe than in Korea, whereas costs in the United States were almost 140 percent higher than Korea. Total direct labor costs for a 54,000 dwt product tanker were 5 times higher in West Germany and 7 times higher in the United States than in Korea. Table 44 reports other relevant data from this study for the end of 1988 and as projected at that time for 1993.

---

4 Refer again to footnote 3.

Table 44. Comparative Inputs and Costs for a 54,000 dwt Product Tanker, Series and Single Production, Actual 1988 and Projected 1993 Data

1988	Japan Series	Korea Series	Germany Single	UK Single	B&W Series	US Single
Labor: Labor-hours/Ship (000's) Hourly Compensation	 376 $19.40	 549 $4.90	 667 $19.40	" 1,087 $11.60	 500 $19.40	 1,316 $14.50
Materials: (000,000's)	$27.7	$22.8	$29.2	$29.2	$29.2	$35.0
Overhead: (000,000's)	$8.2	$7.2	20.7	$14.7	$14.4	$23.2
Production Costs: (000,000's) Labor (% of Total) Materials (% of Total) Overhead (% of Total)	 $7.3 (17) $27.7 (64) $8.2 (19)	 $2.7 (8) $22.8 (70) $7.2 (22)	 $12.9 (21) $29.2 (46) $20.7 (33)	 $12.6 (22) $29.2 (52) $14.7 (26)	 $9.7 (18) $29.2 (55) $14.4 (27)	 $19.1 (25) $35.0 (45) $23.2 (30)
Total (Percent)	$43.2 (100)	$32.6 (100)	$62.8 (100)	$56.5 (100)	$53.3 (100)	$77.3 (100)
1993 Projected	**Japan Series**	**Korean Series**	**German Single**	**UK Single**	**B & W Series**	**US Single**
Labor: Labor-hours/Ship (000's)	341	452	634	1087	431	1135
Materials: (000,000's)	$29.1	$25.1	$30.7	$33.8	$32.2	$36.8
Overhead: (000,000's)	$9.5	$10.1	$21.8	$19.6	$18.4	$28.2
Production Costs: (000,000's) Labor (% of Total) Materials (% of Total) Overhead (% of Total)	 $8.0 (17) $29.1 (62) $9.5 (20)	 $3.6 (9) $25.1 (65) $10.1 (26)	 $13.6 (21) $30.7 (46) $21.8 (33)	 $17.7 (25) $33.8 (48) $19.6 (28)	 $11.2 (18) $32.2 (52) $18.4 (30)	 $21.0 (24) $36.8 (43) $28.2 (33)
Total (Percent)	$46.7 (100)	$38.8 (100)	$66.0 (100)	$71.2 (100)	$61.8 (100)	$86.0 (100)

Source: [Burmeister & Wain, 1989].

b. Productivity and the Building Cycle

Output can be affected significantly by a variety of factors during the life of the ship in the shipyard. By altering these factors so as to reduce the time that the ship spends in production, it is possible to achieve substantial increases in yard output. For example, reducing the time that is spent in the building berth from 6 months to 4 can increase the number of ships built in a year from 2 to 3. Improvements to planning and scheduling can also yield significant increases in output as shown in the calculations below. Interestingly, the calculations also show how few shipyard workers are needed to build commercial ships. Increasing output by 50 percent requires only 295 additional workers.

The effects of improving the ship build cycle are illustrated here.

ORIGINAL BUILD CYCLE		
Start of Fabrication to Keel Laying		4 Months
Keel Laying to Launch (berth time)		6 Months
Launch to Delivery		2 Months
Total Build Cycle		12 Months
Number of Ships per Year	2	
IMPROVED BUILD CYCLE		
Start of Fabrication to Keel Laying		5 Months
Keel Laying to Launch (berth time)		4 Months
Launch to Delivery		2 Months
Total Build Cycle		11 Months
Number of Ships per Year	3	

Using the improved cycle, the number of ships which can be output from the single berth is therefore increased from 2 to 3 per year.

Further assuming that the ship being built is a 40,000 dwt Product Tanker, it would have a Compensated Gross Tonnage of about 18,000. Assuming a productivity rate of 30 labor hours per CGT and 1830 labor hours worked per year (U.S. averages), a shipyard building 1, 2, or 3 ships per year would require the following production labor forces:

1 Ship/Year	295 Employees
2 Ships/Year	590 Employees
3 Ships/Year	885 Employees

If a shipyard has 8,000 employees it will need to build many commercial ships each year, even highly complex types, to keep even half of them productively employed.

One of the best measures of relative productivity (used for more than 30 years) for commercial ships has been labor hours used in processing a ton of steel (Labor hours/ST.WT. Tonne). Representative values are shown in Table 45. This measure incorporates the basic level of productivity in the shipyard plus a complexity factor reflecting the type ship under consideration. Thus, the measure reflects the relative complexity of steel processing which, it can be argued, is essentially what commercial shipbuilders do. It also reflects the efficiency of building larger ships rather than smaller.

Table 45. Labor Hours Per Ton of Steel Constructed

Ship Type	Labor Hours/ST. WT. Tonne
VLCC	16
SuezMax Tanker	19
Product Tanker	27
Chemical Tanker	46
Bulk Carrier	19
Container Ship 4400 TFEU	19
Container Ship 1800 TFEU	28
Reefer	43
General Cargo	56
Ferry	51
Ocean Tug	105

Values for several other measures of productivity are shown in Table 46. While the value for U.S. yards is based on an estimated CGT coefficient, it would need to be off by a factor of four to bring U.S. shipyard productivity into line with that of foreign shipyards. This is unlikely.

Table 46. Other Productivity Measures

	U.S. Yards	Visited Foreign	All Foreign
Labor Hours/Year	1,829	1,805	1,963
Labor Hours/CGT	185	40	88
Cost/Employee Year	$52,500	$63,455	$48,690
Cost/CGT	$5,314	$1,121	$1,296

Another indicator of output efficiency is how long a ship is under construction; representative data are shown in Table 47. Denmark and Japan are leaders in production and rapid delivery of ships

Table 47. Construction Time in Months Keel Laying to Delivery

Ship Type	Europe	Denmark	Japan	U.S.
VLCC	17	5	9	
Product Tanker	12		8	20
Bulk Carrier	16		8	
Container Ship 4400	17	8	9	
Container Ship 18880	12	12		24

These are not exact measures of productivity but are indicators that the best shipyards minimize the time a ship is in the building dock. This permits a more efficient use of limited building dock space—other things being equal, this means greater productivity.

Table 48 shows a hypothetical breakdown of the costs of the inputs for a 40,000 dwt product tanker. These are estimated minimum costs for the first ship in a series. This table shows about $20 million before labor and capital charges are added. If this ship is part of a two ship per year series, then we have $20 million plus capital costs of $4-5 million, plus labor costs. If labor is $30 per hour and it takes 1 million labor hours to build a ship, we are looking at a total first ship cost of $55 million to $60 million.

Table 48. Materiel Breakdown for a Notional 40,000 dwt Product Tanker

Item	Description	Cost Estimated $M
1	Steel Plates/Shapes	4.5
2	Foam System/Carbon Dioxide System/Lifeboats and Davits	0.7
3	TP Propeller & Shafting	0.2
4	FO and LO Purification Modules	0.1
5	Cargo and Ballast Systems Equipment	2.0
6	Inert Gas Generator Plant	0.3
7	Diesel Generator Sets	1.0
8	Anchor Windlass/Mooring Winches	0.4
9	Main and Emergency Switchboards	0.3
10	Coatings	0.4
11	Steam Generating Equipment	0.6
12	Classification Services	0.5
13	Propulsion Diesel Engine	3.0 - 4.0
14	Joiner Package	1.4
15	HVAC	1.0
16	NAVCOMS & Controls	1.0

D. NEWBUILDING PRICES FOR PRODUCT TANKERS

1. Estimating Product Tanker Prices: The Difficulties

Prices for newly built product tankers are set in an intensely competitive world market. The demand function is formed by shipowners on the basis of the following:

- Expectations of shipping rates
- Extents and terms of their long-term contracts
- Projected replacement of materially or economically obsolescent product tankers
- Overhang of second-hand product tankers in the market
- Availability and terms of investment funds
- Economics of substitutability of crude product tankers for product tankers
- Movements in the exchange rates of world currencies
- Prices at which such product tankers are available.

The aggregate supply function is the result of the costs of labor, materials and overhead, which, as indicated earlier, vary substantially among international shipyards, largely as a result of the following:

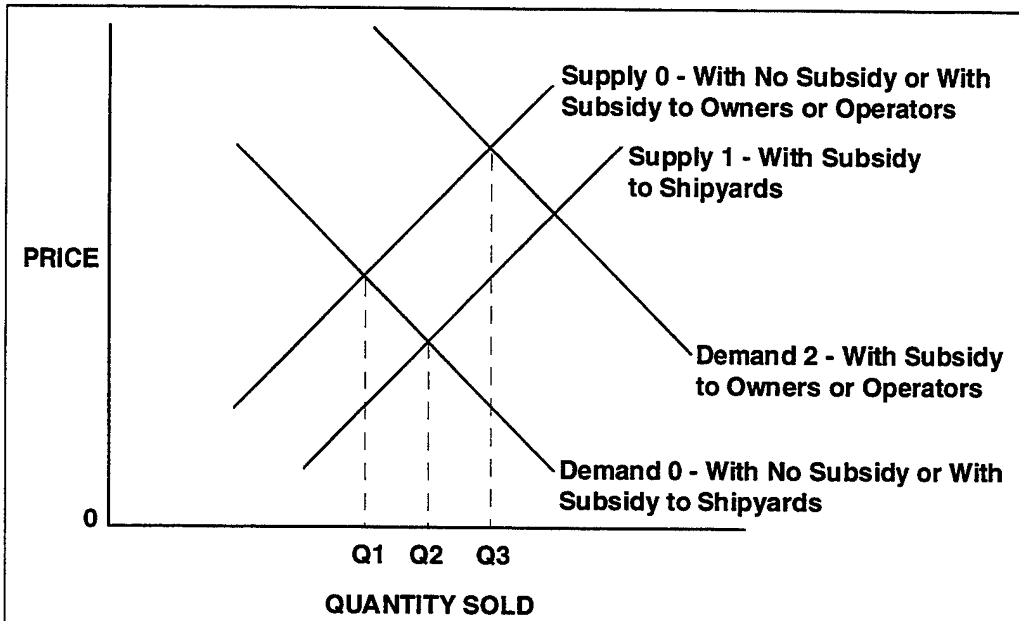
- Differential wage rates and factor productivity as well as new investment costs
- Specifications of customers and the quality of the product provided
- Current and expected movements in exchange rates of own currencies
- Existence or availability of usable designs and their flexibility in terms of customer specifications
- Skill of management in production and marketing.

But there is a third set of players in the market of especially large importance in shipbuilding: governments. Desiring to retain employment and perhaps a historic tradition in the shipbuilding industry, nations have, in recent years, increased their reliance on subsidization to previously unmatched levels. Government support for shipbuilding includes:

- Direct support to permit ship dumping below production costs
- Providing loans to ship owners to construct ships with varying levels of interest subsidies
- Loan guarantees
- Export credit insurance
- Capital infusions to domestic yards to prevent bankruptcy or facilitate mergers
- Government purchase of obsolescent capacity
- Research and development finance
- Grants and loans to less-developed-countries for purchase of ships
- Purchase of equity capital with repair of capital structure when necessary.

In subsection 2 below, the extent of such market intervention and its effects on competitiveness are estimated. The impact of the intervention on the market can be built into the demand and supply structure by shifting the functions appropriately (see Figure 21). The demand curve shifts to the right (at every market price of product tankers, shipowners will buy more when a subsidy is in effect than when it is not if the subsidy is designed for their benefit) or the supply function shifts to the right (at every market price

shipbuilders will be willing to supply more product tankers when a subsidy is in effect than when it is not if the subsidy benefits them directly) or some combination of effects.



NOTE:
If no subsidy, quantity sold = Q1
If subsidies go to shipyards, there will be no effect on the demand schedule but more ships will be sold (Q2).
If subsidies go to owners or operators, there will be no effect on the supply schedule but more ships will be sold (Q3).
If subsidies are divided between shipbuilders and owners or operators, price and quantity become indeterminate.

Figure 21. Notional Illustration of Economic Effects of Subsidies

Interestingly, these shifts tend to offset one another in terms of their impact on market price. The quantity of ships sold will always rise, but market price may rise, fall or remain constant depending upon the distribution of subsidies between shipowners and shipbuilders and the slopes of the two curves with regard to price. Hence, if market prices of product tankers are declining this may merely disguise the fact that subsidies to shipbuilders have increased, not that expectations of shipowners of the profitability of product shipping has declined. Government intervention, therefore, makes the movement of prices ambiguous, since they may outweigh changes in the expectations of shipowners and shipbuilders which will also shift the curves.

The analysis underlines the extremely complicated and perilous task of forecasting market prices for product tankers, even for intermediate term predictions. The complex

factors that enter into the formation and alteration of shipowner expectations and consequent actions, the difficulties in costing the production of shipbuilders' efforts, and the isolation and projection of subtle governmental market interventions are complicated further by the uncertain results of their mutual interdependence. The risk-averse producer and consumer of such research must trod warily. Even with all these variables, the price of product tankers has been one of the more stable ship price measures during the past decade.

This subsection has dealt with the comparative costs among world shipyards; the results show that these costs are a major factor behind the builders' supply functions. Subsection 2 below is devoted to projections of product tanker prices over the future, which, as noted in subsection 1 above, involves a judgment of the net resultants of demand, supply and subsidy forces. Finally, in subsection 3, the types and extents of subsidies offered shipowners and shipbuilders are examined and the various governmental purveyors of these subsidies are identified.

2. Price Projections for Product Tankers

Projection of product prices in a stable market for a national economy over a short or intermediate time period is a risky enterprise at best. The task of forecasting dollar prices for a long-lived product whose demand fluctuates with dramatic cyclical amplitudes, in an international market with a large second-hand overhang and with currencies subject to differential valuations, and in industries in which governments adopt active "industrial policies" effectively involving subsidies of an infinite variety or projectionist legislation, approaches the foolhardy. Researchers— and particularly those who are most knowledgeable about the industry— invariably present their results with caveats.

Because the demand for new building is a derived demand from the demand for shipping services and the age structure of existing ships, forecasting usually begins with predictions of shipping demand and estimated replacement needs for ships over the forecast period. That methodology is standard among forecasters to derive some estimate of annual demands, and must be complemented by a cost study. The interfacing of demand and costs yields some notional market price, but it must be discounted by the maximum subsidization envisaged over the set of relevant governments.

Some recent forecasts using this methodology include those published in 1993 by Ocean Shipping Consultants, Ltd., of London, one of the most respected consultant houses covering the shipping and shipbuilding industries worldwide.[5] These are shown in Table 49. The forecast period is 1980-2005 and prices over that period are projected to rise for a 30,000 dwt product tanker from $29 million in 1993 to $41 million in 2000 and $42.5 million in 2005. Prices are projected to turnaround about 1995 and peak in 2004, at about $44.5 million, then begin a decline. The incremental rise forecast in 1995 has not yet materialized, but prices of product tankers have held steady throughout the year.

Table 49. Forecast Product Tanker Newbuilding Prices, 1993-2005 (Millions of 1993 Dollars)

	Product Tanker 30,000 dwt	VLCC 250,000 dwt
1980	24.5	51.0
1985	14.0	39.0
1990	29.0	87.9
1993	29.0	81.7
2000	41.0	114.0
2005	42.5	121.0

Source: Ocean Shipping Consultants Ltd.

The projections shown in the table above are extensions of forecasts made by OSC [Ocean Shipping Consultants, 1990] and terminating in 2000. In that report product tankers of 50,000 dwt are projected to rise in price (in 1990 dollars) from $44 million in 1995 to $50 million in 2000 for the base case. Upper bound estimates of $48 million in 1995 and $53 million in 2000 are projected, with lower bound estimates of $40 million for both years. Variances of such magnitude are indicative of the considerable uncertainty involved in such exercises.

---

5 See [Ocean Shipping Consultants, 1993], pp. 261-281, for relevant data. Note especially the caveats on p. 261:

> "Thus, in general, few owners are likely to order new tonnage if freight market prospects are for significant charter rate decline. There is therefore, a freight market/newbuilding price linkage, the precise nature of which is impossible to determine.
>
> "Furthermore, . . ., the significance of changing exchange rates can be crucial in any overall profile of development. Inevitably the development of relative rates of currency exchange lies well outside the scope of this Report --forward prices are based on current (early-1993) prevailing rates of exchange."

In deriving these forecasts, OSC stresses three dominant factors. First, despite the relative stagnation in the worldwide consumption of petroleum since the OPEC measures of the 1970s, demand is increasing rapidly in Southeast Asia, Latin America, and, to a lesser extent, Africa. The necessary increase in tanker capacity to serve these rising needs should outpace slower growth in such needs in the OECD and other developed countries, benefiting demand for tankers in general and product tankers as well.

Second, refining capacity has declined significantly in the 1980s in the developed world as petroleum exporting countries have increased their downstream activities. A growing proportion of petroleum exports, therefore, is expected to be in product rather than crude form, which should give an independent boost to product tanker newbuilding.

Third, although on an overall basis world shipbuilding capacity is sufficiently large and structurally capable of supporting product tanker production, it is necessary to consider the competition that other ship types will offer for building space. OSC estimates that although perhaps 20 percent of total world shipbuilding capacity is product tanker capable, only about 1.3 million CGRT could be switched currently to such production without disrupting other building programs. [Ocean Shipping Consultants, 1990]

However, given projections of other types of newbuilding, this "excess capacity" is projected to shrink to 0.6 to 0.7 million CGRT in the first half of the 1990s and to less than 0.4 million CGRT in the second half, and then to decline further to 0.2 million CGRT by 2000. This shrinkage should place upward pressure on prices for product tankers.

In this regard, a last consideration leads one to expect that the portion of excess capacity that is most directly instrumental in putting pressure on market prices will be even further reduced. A significant portion of product tanker construction—between 30 and 40 percent—over the decade 1990-2000 will be tied to "captive" shipyards. These are yards that are state-owned or in which shipowners have substantial equity, and hence whose product tanker production will not be obtained through a market. Therefore, the amount of "untied" excess capacity is expected to shrink even more, especially in the latter half of the period, to negative or near-zero positive levels.

Substantial upward pressure on prices is therefore to be expected, a portion of which should be relieved by shipyards shifting capacity toward product tankers. Nonetheless, expectations of positive net price influence underlie the estimates.

3. Government Subsidies and Adjustments of Market Prices

Unfortunately, as noted in the introduction to this chapter, the net prices of new ships to customers are not wholly market determined. Governments are active players in the industry, both in tying domestic sales to state-owned or protected domestic yards and in subsidizing sales to foreigners.. The goals of protecting jobs and preserving shipbuilding for national security or maintenance of tradition combine to make this industry one of the most government-pampered in the world.

A variety of measures is adopted to protect domestic shipyards: cabotage laws, import tariffs and nontariff restrictions, and tied sales are major tools. Budgetary aid is extended in the form of loans to buyers, interest subsidies, loan guarantees, contract grants to shipyards or shipowners, provision of shipyard capital, loans to yards, subsidies on interest payments by shipyards, and support of research and development. The data are inexact, as many subsidies are hidden in their awards and/or amounts, but the importance of such rewards cannot well be disputed. A recent review of four previously published studies [Cummiskey, 1990] concluded that Japan's subsidies reduced price below cost between 11.25 and 45 percent in the depressed years 1982 to 1989. These subsidies do not include modernization payments to Japanese shipyards.

Subsidization during the 1980s became massive as newbuilding slumped worldwide in the wake of OPEC price fixing. The Reagan administration, however, took steps to eliminate U.S. subsidies and protection by terminating the Construction Differential Subsidy (CDS) program, which compensated U.S. flag shipowners for a substantial portion of the higher costs of U.S.-built ships, as well as amending Section 615 of the Merchant Marine Act. This allowed U.S. flag operators to receive Operating Differential Subsidy (ODS) payments for the higher costs of operating these ships with U.S. crews even if they bought ships from foreign yards.

A growing awareness, fed by U.S. discontent, that the subsidization programs were destabilizing the international industry led to a variety of efforts to constrain the programs within the Organization for Economic Cooperation and Development (OECD). In 1983 14 OECD nations agreed in the Revised General Agreement to forego new shipbuilding subsidies and gradually eliminate existing ones. Absent an enforcement procedure, the signatories promptly ignored it. Table 50 shows the amount of subsidies provided to shipbuilders by the leading shipbuilding nations.

Table 50. Average Annual Shipbuilding Aid Budgets of Top Subsidizing OECD Nations Since 1988

	Ship Financing		Direct Yard Aid				
Nation	Loans, Interest Subsidy	Guarantees	Contract Grants	Shipyard Capital	Yard Loans, Interest Subsidy	R&D	Annual Average
S. Korea	$1.8 B	Yes	Unknown	Yes	$595 M	Yes	$2.4 B
Germany	$1.5	Yes	$353 M	$463 M	Yes	Yes	$2.3 B
Japan	$818 M	Yes	Some	$85 M	Yes	$1 B	$1.9 B
Italy	$557 M	Unknown	$175 M	$184 M	Unknown	$24 M	$940 M
Spain	$306 M	Yes	$153.5 M	$438.2 M	Yes	Yes	$897 M
France	$399 M	Yes	$149 M	$83 M	Unknown	$3 M	$643 M

Source: [Shipbuilders Council of America, 1993]. The annual averages exclude the value of loan guarantees.

Subsequent OECD negotiations to revitalize the program collapsed and in June, 1989, the SCA petitioned under Section 301 of the U.S. Trade Act on behalf of U.S. shipbuilders for protection against the subsidies. U.S. Trade Representative Carla Hills persuaded SCA to drop the initiative in return for initiating negotiations in the OECD. Despite assurances that an agreement could be reached in nine months, no agreement ensued and in April, 1992 negotiations were suspended.

A bill to threaten retaliation against subsidies was passed by the House of Representatives in 1992 but stalled in the Senate, and such legislation was introduced again in 1993. The OECD did reach agreement in 1995 that subsidies will be phased out, beginning in January 1996. It appears at the present time that a serious reduction of present forms of subsidies in Europe, Japan and Korea will begin at that time. U.S. shipyards attempting to compete with European and Asian yards can look forward to support mainly from Title XI guarantees by the Maritime Administration of loans for the purchase of U.S. built ships. In the words of the SCA, whose major emphasis in recent years has been on a campaign to eliminate foreign subsidies:

> ". . .the transition to building commercial ships cannot be successful unless foreign shipbuilding subsidy practices are terminated." [Shipbuilders Council of America, 1993]

E. POTENTIAL SPILLOVER EFFECTS FROM COMMERCIAL SHIP-BUILDING TO NAVY SHIPBUILDING

In this section we examine the potential effects on naval shipbuilding that might devolve from increased construction of commercial ships. In particular we address the following questions: what are the potential feedbacks from the commercial shipbuilding sector to navy shipbuilding activities? What sorts of neighborhood effects or externalities of a positive or negative kind might be forthcoming were commercial and Navy shipbuilding to operate as complementary activities in U.S. shipyards? Obviously, if shipyards can build both naval and commercial ships, this will improve the utilization of the facilities keeping them in a productive status for naval ship production.

Of greatest significance in these respects would be the beneficial effects on naval shipbuilding efficiency that would flow from the reorientation of management thinking that will be necessary to enter the commercial market successfully. The emphasis upon performance and schedule that characterizes management concerns currently in naval contracting and shipbuilding may be altered significantly to give greater consideration to costs. This would reduce the overhead charge on naval ship construction in management labor and fixed charges.

Experience in the commercial area should give management a greater concern for the tradeoffs between cost and performance, cost and schedule, and performance and schedule. This would imply more attention to analyzing and measuring these tradeoffs, and to making more effective presentations to the Navy. In general, increasing costs as performance parameters rise toward current upper bounds inflict much more than linear dollar penalties. Slight increases in tolerance parameters can yield large cost reductions. Technological proficiency can now be rescaled in relation to that possessed by potential rivals, and some realization in performance standards permitted.

The use of improved production techniques and innovative technologies in ship construction developed for commercial ships might well be helpful where applicable to naval ship production. Insofar as building more ships (of both naval and commercial) enables a shipyard to realize scale economies in purchasing, the total cost of the ship may be less. This activity might also contribute something to keeping suppliers more kindly disposed toward the shipbuilding industry.

Shipyards with commercial opportunities can continue to develop more off-line construction facilities and techniques which are also applicable to naval ship building.

Shipyards should also be more alert to the schedule costs of maintaining higher-than-necessary performance aspirations. Besides the higher costs of more complicated material and the request slippage's in delivery times due to engineering failures with entailed shipyard disruption costs, such desires for unnecessary technological improvements result in costly change orders and ripouts. Such disruptions have ripple effects on multiple schedules throughout the yard whose quantification is difficult and in itself adds litigation costs to direct costs.

An additional benefit of increased commercial ship building should be to encourage the use of commercial grade components in naval ships, provided they meet naval ship requirements. Alternately, naval requirements could be modified so that commercial equipment is satisfactory.

Insofar as commercial shipbuilding uses some existing capacity, the facility can be maintained as part of the "warm base" of industrial preparations. A key core of specially skilled workers can also be maintained as part of maintenance of a "warm industrial base" in shipbuilding.

F. FINDINGS

1. The Economic Case for Commercial Shipbuilding

Based on the assessment presented in the preceding sections, it is apparent that naval shipbuilders will have to consider a number of critical factors before deciding whether to add, or shift to, commercial production. In particular increasing production of commercial ships will require transition to a much more cost conscious approach and perhaps even the adoption of Japanese or Scandinavian methods of management. Yards will have to shift the work force somewhat in the direction of lower skill structural work, increase the size of their steel yards and add more handling and robotic welding techniques, and provide large enough areas for pre-assembly in proximity to final assembly. In summary, the U.S. shipbuilders will need to consider the following factors:

- In the postwar period the United States has never had a presence in this market. Marketing and production skills at the major U.S. shipyards have been concentrated upon naval ships with emphasis upon performance

specifications rather than costs. Smaller shipyards have specialized in repairs and conversions, with some construction of smaller vessels for domestic coastal and riverine usage or for relatively small numbers of Jones Act intercoastal vessels. Most especially, marketing organizations and distribution networks would have to be created with completely different orientations and skills, and require major adjustments in the thinking of emplaced managements and personnel that has proved extremely difficult in similar contexts.

- U.S. shipbuilders planning to enter the commercial market will have to consider the following factors:
  - marketing
  - development of standard ship designs
  - material management
  - steel handling
  - application of new technologies in welding and steel block assemblies
  - human resources - scaling down the complex skills to a simpler skill workforce
- Shipbuilders must shift from producing naval ships, which typically require several million labor hours to build, to building commercial ships that, if built competitively, must be manufactured for 500,000 to 600,000 labor hours or less
- The absence of the U. S. industry from international shipbuilding has meant that its naval architects in the postwar period have not acquired expertise in the design of commercial oceangoing ships. The industry does not have a library of designs for such ships which are standardized but flexible enough for customization to meet customer demands, and which are built around standardized modules that can be employed in a variety of ship classes. It will be dependent, therefore, upon existing commercial shipbuilders for such designs if it is to enter the international market in earnest.
- Far from being technologically advanced in commercial shipbuilding and capable of embarking on complex ship production, the United States begins with severe disadvantages in such technology even when confronted with competitors like Korea or Poland which in most other pursuits considerably lag the United States. Skills in computerized commercial ship design, robotized and closely time-phased production processes, modularized mass production techniques adapted to commercial ship production, machinery

specialized to shipside production methods, networks of component suppliers and subcontractors skilled in commercial ship needs and closely integrated with shipyards: all must be developed *ab ovo* while facing experienced incumbents in the industry. As noted previously, most U.S. shipbuilders have given some thought to the possibility of constructing commercial ships. Thus far, however, only Avondale and Newport News have actually won commercial contracts. Ingalls, though clearly as capable as these firms, has made a strategic business decision to stay out of the commercial market at least for the near term.

- Shipbuilding labor in the United States is costly in many respects. Turnover historically has been very high. The labor is disagreeable in being cramped, noisy and hot, especially for younger workers who are not accustomed to such conditions. Much of the production labor force is engaged in activities which are essentially construction labor highly substitutable for residential and commercial construction outside the yard. When such activity enters an upswing period in its cycle, shipyard workers tend to leave the yards for more attractive jobs on the outside. Educating shipyard labor forces in the face of such turnover is costly, therefore, and an important indirect labor cost. High productivity in the U.S. labor force in general is not high in U.S. shipyards and is excelled in Japanese and some important European shipyards, and is potentially if not actually so in Korean yards.

- Newbuilding is cyclical and characterized by large amplitudes. Ships are major investments and highly durable, so that replacement can be postponed for long periods. The second hand market exists to offer alternatives to newbuilding in periods of financial stringency or uncertainty for shippers. Existing stocks can be used more intensively when demand for shipping services rises. And the underlying demand for shipping services from which newbuilding is derived reveals a history of uncertain forecast. An attempt to build essentially from a low base in commercial shipbuilding on the basis of current expectations of a rise in the newbuilding cycle may, for private yards, involve substantial investments that may in the medium run prove burdensome and lead to bankruptcies for some firms when the cycle stabilizes and enters a downturn. Such firms may be rationally risk-averse and reluctant to commit private funds to such purposes.

- On the scale of complexity, commercial shipbuilding is essentially a steel-fabrication and assembly industry whose technology is not difficult to acquire for a nation that has reached a stage of development where necessary investment is available. As less developed nations, therefore, are ready to move beyond textile production into more capital intensive pursuits it

becomes a logical choice for adoption. The pattern that is revealed in the industry fits these characteristics: Sweden has abandoned shipbuilding completely, Great Britain over the last decades has phased out as many of its shipyards as has been politically feasible. The European Union has been engaged in some time in trying to rid the industry within its borders of excess capacity. Japan, having adopted shipbuilding as an emerging economy in the postwar period is now in active competition with Korea which entered this phase of development later, and Korea will in the near future no doubt confront China and Brazil as they emerge. High-technology nations facing such relocation fundamentals typically yield to their economic force and permit the industry to die a natural death, move into more demanding niche products within the industry or else petition their governments to erect protectionist barriers or to subsidize their outmoded facilities. The United States has in the past engaged in the latter practice in shipbuilding with the Construction Differential Subsidy.

- The international shipbuilding industry is a hugely subsidized industry by nations who have had a long tradition of government participation in one guise or another in their industrial sectors. The strength of the United States economy springs in large part from the fact that government has not interfered with the decisions of the market economy to rigidify labor-management relations or to interfere with the adjustments of industries to changing economic conditions. It does not have a tradition of active "industrial policy", even when the only rational adjustment that an industry can make is to die or to shift reduced capacity into newer forms of product within the industry. Two implications flow from this observation. First, the United States will always be a reluctant and therefore less-skilled player in the game of subsidization and protectionism. And, second, hopes for success in the current U.S.-led drive to eliminate subsidization from international shipbuilding are to say the least less than a prudent basis upon which to establish a new commercial shipbuilding base.

- The basic economic reality in the 50-year postwar period—that the major players in the shipbuilding industry have formed a defense industry and should and ultimately will join other such industries in making the peacetime adjustment—should be accepted when economic policy measures are considered. Mergers and consolidations among the major shipyards with downsizing of capacity and labor force are worth serious consideration in order to concentrate the reduced Navy demand into viable facilities. This recognizes the possibility that some of these merged yards may be able to enter niche markets in the commercial shipbuilding industry, essentially as a companion activity to naval shipbuilding, with exploitation of the economies

of scale and scope that arise from the joint defense-commercial production. This smaller body of more viable firms would be led to increased partnerships with foreign firms to share technology, designs, suppliers and facilities to reduce costs and increase efficiency.

- Economically speaking, the purpose of economic activity is to produce useful goods and services—not to produce jobs. The strength of the political temptation to protect outmoded industries to preserve jobs need not be argued, but it is always an *economic* mistake, delaying long-term adjustments that will ultimately prove necessary and preventing efficient allocation of resources. Other means of more fruitful relief for the unemployed will exist and should be adopted in lieu of placing obstacles to adjustment. Numerous examples can be cited, but most recently the recovery of the New England economy from what was viewed in the 1950s as the devastating loss of the textile industry and the revival of the "Rust Belt" from the pervasive structural changes of the 1970s and early 1980s which at the time were viewed as crippling are two whose scale far exceeded the displacements that reducing capacity in shipbuilding would entail. This is especially true because of the historical mobility of the shipbuilding labor force between the industry and other construction activities.

Based on these considerations it is concluded that the United States possesses no evident advantage when compared with internationally-established shipbuilders and consequently that there is little economic motivation for devoting significant investment to establishing a commercial shipbuilding industry. The excess capacity that has characterized the industry worldwide in recent years and led other developed nations to downsize further argues that major U.S. government investment would be counter to worldwide trends. Like other defense industries, large shipyards capable of long-hulled production should downsize and consolidate to preserve naval construction viability. In addition, they should develop niche-market capabilities where practicable as specialized or limited players in the commercial market. Although some U.S. shipbuilders have made substantial progress toward this goal, the ultimate success of their efforts is yet to be established. Large scale subsidization of excess capacity in the industry runs counter to U.S. economic practice and damages the economy in the long run, and hence cannot be recommended.

2. The National Security Case for Shipbuilding

The foregoing analysis examines only the economic issues regarding the establishment of a competitive commercial shipbuilding industry in the United States. It neglects the most potent reason for the proposal: the national security goal of keeping a warm base for naval shipbuilding capable of expansion should major changes occur in the global strategic environment. A reasonably sized shipbuilding base also facilitates competition and thereby constrains costs for naval ships. Of course, the national security goal may be judged of primary importance for the public good and thus to have priority that overrides the economic considerations. The economist's response to such argument is to recognize its legitimacy, but to urge that alternative means of achieving such a capacity be subjected to cost-benefit analysis in economic terms. With that purpose in mind, it is hoped that the following brief remarks will cast some light on these issues.

The conclusion of this assessment is that providing a continuing production capability for naval combatants and auxiliaries is going to involve national subsidies in one form or another, whether indirectly through government support for increased commercial production or directly through some type of support for naval shipbuilding. Consequently, the policy debate must revolve about the sizes of such subsidies implied by the alternative policies and the manner of effecting them. Based on the arguments presented earlier, relying on commercial shipbuilding to preserve capability is likely to be a fairly expensive way of achieving that goal. Moreover, to the extent that such a program involves indirect expenditures, its application is likely to disguise the true cost from both the public and policy makers. On the grounds that subsidies should be minimized and visible, a policy involving indirect expenditures should not be adopted.

Instead it is urged that a variety of alternatives be addressed, including outright payments from the defense budget to a subset of yards whose potential for Navy construction is judged vital to the national interest; the possible purchase of that subset of yards by the government to form a notional government shipyard managed by private firms; or the annual payment to firms in that subset of contractual amounts as *option demand*, which is a recognition of the government's right, if necessary, to call upon these yards' capacity to provide such ships, on an agreed contractual basis. This study does not

prejudge the wisdom of any of these alternatives, nor does it render final judgment on their desirability *vis á vis* fostering commercial shipbuilding. It is recommended that such alternatives and others not suggested be studied before adopting the commercial shipbuilding means of providing the desired base.

This page intentionally left blank

REFERENCES

1. A & P Appledore, International, Ltd., London, 1995, presented to the US MARAD, June 11, 1995.
2. Landsburg, A.C., A. Jenks, S. Lee, and E.B. Schimler, "Analysis of Japanese and Korean Shipbuilding Prices," *Marine Technology*, 25 (1988/1), pp. 44-66.
3. Landsburg, A.C., E. Gabler, G. Levine, R. Sonnenschein, and E. Simmons, "U.S. Commercial Ships for Tomorrow," *Marine Technology*, 27 (1990/3), pp. 129-52.
4. Burmeister & Wain Shipdesign ApS, *World Market Prices and Production Costs of Larger Cargo Ships*, Copenhagen, January 1989.
5. "Capital for Shipping 1992," *Lloyd's Shipping Economist*, Financial Overview, 1993, pp. 5-11.
6. Carson, J.P. and B. Lamb, *U.S. Commercial Shipbuilding in the 1990s: The Global Context*, Temple, Barker and Sloane, Inc., 1990.
7. Goldrein, I.S. et al., eds., *Ship Sale and Purchase*, Lloyd's of London Press: London, 1993.
8. Fetchko, J.A., *Methodology of Estimating Initial Investment Costs of Ships*, unpublished, University of Michigan, Ann Arbor, June 1968.
9. Cummiskey, J.W., *United States Commercial Shipbuilding Productivity: An International View*, Monterey: U.S. Naval Postgraduate School, December 1990.
10. Ocean Shipping Consultants, Ltd., *Product Tankers: Demand and Profitability to 2000*, Chertsey, U.K., undated.
11. Ocean Shipping Consultants, Ltd., *Product Tankers: Future Newbuilding Demand and Prices*, Chertsey, U.K., September 1990,
12. Ocean Shipping Consultants, Ltd., *The World Shipbuilding Industry: Activity & Prices, 1994-2005*, Chertsey, U.K., 1993.
13. President of the United States, *Strengthening America's Shipyards: A Plan for Competing in the International Market*, Washington, D.C., October 1, 1993.
14. Rost, R.G. and C.E. Tighe, *Shipyard Costs and Capabilities* (U), Center for Naval Analyses, Alexandria, Va., 1992.
15. Shipbuilders Council of America, *International Shipbuilding Aid*, Arlington, Va., June, 1993.
16. Shipbuilders Council of America, *MARITECH Awards for FY1994*, Arlington, Va., May 25, 1994.

17. Shipbuilders Council of America, *Product Tankers: Future Newshipbuilding Demand and Prices*, Arlington, Va., September 1990.

18. Shipbuilders Council of America, *Status of the U.S. Shipbuilding Industry*, Arlington, Virginia, undated.

19. Shipbuilders Council of America, *The Transition of American Shipyards to Commercial Markets*, Arlington, Virginia, February 24, 1994.

20. Storch, R. L., J. Clark, and T. Lamb, *Technology Survey of U.S. Shipyards-1994*, Society of Naval Architects and Marine Engineers, Paper presented at 1995 Ship Production Symposium, Seattle, January, 1995.

21. U.S. Department of Transportation, Maritime Administration, *Report on Survey of U.S. Shipbuilding and Repair Facilities*, 1993, Washington, D.C., 1994.

Appendix A

PROGRAM HISTORIES

APPENDIX A
PROGRAM HISTORIES

A. AOE 6 SUPPLY CLASS SUPPORT SHIPS

The AOE 6 support ship (Fast Combat Support Ship) is designed to operate as part of a carrier battle group. It can deliver on-station munitions, bulk fuel, and other provisions for a carrier battle group underway in a hostile environment. The ship also delivers and receives fleet freight, mail, and personnel to and from combat forces underway.

The AOE 6 supply class is equipped with the following subsystems:

- Missiles: SAM Raytheon GMLS Mk 29 octuple launcher, and NATO Sea Sparrow.
- Guns: 2 General Electric/General Dynamic 20-mm Vulcan Phalanx Mk 15, 2 Hughes 25-mm Mk 88 and 4 12.7-mm machine guns.
- Countermeasures: Decoys 4 Loral Hycor SRBOC 6-barreled Mk 36; IR flares and chaff. Nixie torpedo decoy.
- ESM/ECM: SLQ 32(V)3; combined intercept and jammer.
- Fire Control: Mk 91 MFCS
- Radars: Air Search: Hughes Mk 23 TAS; D band. Air/Surface Search: Norden SPS 67; G band. Navigation: Raytheon SOS 64(V)9; I band. Fire Control: 2 Raytheon Mk 95; I/J band. Tacan: URN 25.
- Helicopter: 3 UH-46E Sea Knight.

The AOE 6 program was approved by a Navy Decision Coordinating Paper dated March 1986. NASSCO was awarded the lead ship detailed design and construction contract in January 1987. The contract was a fixed-price incentive type for one ship with an option for three additional ships. The contract had an escalation clause, and there was a 50/50 share line. Options for the first 2 follow ships were exercised in November 1988 and December 1989, respectively. The option for the third ship (AOE 9) was allowed to

lapse, but two years later the AOE 10 was added to the program. NASSCO was awarded a fixed-price incentive contract subject to escalation, with a 50/50 share.

The program was plagued with funding and planning turbulence. The Congressional budget of February 1991 reduced the AOE 6 class program from 7 to 4 ships. The AOE 9 (the FY91 ship) was rescinded, and an AOE 10 was added for FY93.

Fifth and sixth ships were later added in January 1993, increasing the AOE 6 program to 6 ships. In January 1994, the Congressional budget dropped the last 2 ships for a current plan of 4 ships.

The contractor had financial problems and advised NAVSEA in February 1991 that it would have to file for bankruptcy unless there were government assistance. The Navy provided $25 million in funding shortly thereafter, and Congress voted an additional $237 million in May 1991 under a supplemental appropriation. There were large contractor claims associated with late delivery of government-furnished equipment, the Reversing Reduction Gears (RRG)s for the AOE 10, resulting in a loss of learning and inefficiencies due to the large workforce required.

The acquisition initiatives applied to the program were incentive contracts in development and in production. The lead ship was designed and constructed under a fixed-price contract, which is close to fixed-price development.

The program was baselined fairly late in the process for a major acquisition program. While Milestone II occurred in October 1986, the only program baseline in the SAR is a production estimate dated March 1986 in the first SAR, 17 months after the Milestone II equivalent date. Because the baseline was established later than usual, we expect that the baseline would reflect more knowledge of actual costs. Thus, cost growth should be lower. However, even with the advantage of the late baseline, cost growth for this program is a relatively high 30 percent. Among the reasons for this outcome are the cutback in the program from 7 to 4 ships, problems with the contractor's financial stability, and other problems.

Despite considerable cost and schedule problems, the program met its technical goals.

B. CG 47 TICONDEROGA CLASS CRUISERS

The CG 47 Ticonderoga class cruisers perform antiair, antisubmarine, and antisurface warfare, and strike against surface targets, as part of an aircraft carrier or surface task force. The cruisers were built by Bath Iron Works and the Ingalls Shipbuilding Division of Litton Industries and are among the most advanced surface combatants in the world. The ship is a modification of the DD 963 Spruance class destroyer, with the addition of the AEGIS air defense system and different armament. Like the DD 963 class, the CG 47 class has four General Electric LM2500 gas turbines on two shafts with controllable reversible pitch propellers.

The CG 47 is equipped with two FMC MK 26 MOD 5 missile launch systems on hulls 47 through 51, and two FMC MK 41 vertical launch systems on subsequent hulls. The launch systems are for firing the General Dynamics RIM-66 Standard Missile 2–Medium Range for antiair warfare, Honeywell RUR-5A antisubmarine rocket for antisubmarine warfare, McDonnell Douglas RGM-84 Harpoon missile for attacks against surface targets, and General Dynamics BGM-109 Tomahawk missile for attacks against surface and land targets.

For antiair warfare, the CG 47 class is equipped with the following subsystems:

- General Electric RCA Government Systems Division MK 7 MOD 3 AEGIS weapon system, with General Electric/RCA SPY-1A radars on hulls 47-58, and the Raytheon SPY-1B radar, UYK-21 displays, and UYK-43/44 computers on subsequent hulls
- Lockheed SPQ-91 fire control radars on earlier hulls, followed by Raytheon/RCA SPG-62 fire control radars on later hulls
- Raytheon AN/SPS-49(v)7 air search radar
- General Dynamics MK 15 MOD 0 or MOD 2 Phalanx close-in weapon system.

For antisubmarine warfare, the CG 47 class is equipped with the following subsystems:

- Singer Librascope underwater fire control system MK 116 MOD 6
- General Electric/Hughes AN/SQS-53A/B hull-mounted active search and attack sonar on hulls 47-55, replaced with the General Electric AN/SQS-53C on subsequent hulls

- Gould AN/SQR-19 passive towed sonar array on hulls 47-55, replaced with the Gould AN/SQQ-89(v)3 on subsequent hulls
- LAMPS MK 1 helicopter on hulls 47-48, replaced with the LAMPS MK 3 on subsequent hulls
- 324 mm MK 32 torpedo launcher
- Honeywell MK 46 Mod 5 or Honeywell MK 50 torpedo.

For antisurface warfare and strikes against land targets, the CG 47 class is equipped with the:

- ISC Cardion AN/SPS-55 surface search radar
- FMC 5-inch/54 MK 45 gun (Mod 0 on CG 47-50 and Mod 1 on CG 51 onwards)
- TAINS (TERCOM-aided navigation system) to 2500 km (1400 nautical miles)
- TOMAHAWK cruise missiles fitted with 200 kT nuclear warhead (TLAM-N), 454-kg conventional blast warhead (TLAM-C) or submunitions (TLAM-D). Range increased by 30 percent in TLAM-C Block III, production of which started in 1992.
- General Electric/General Dynamic 20-mm Phalanx 6-barreled Mk 15 gun system.

The CG 47 class is also equipped with the:

- Raytheon AN/SLQ-32(v)3, for electronic warfare
- Hughes Aircraft Navy Tactical Data System Links 4A, 11, 14, and 16; SATCOM SRR-1; WSC-3 (UHF), USC-38 (EHF); UYK 7 and 20 computers (CG47-58); UYK 43/44 (CG 59 onwards); and SQQ 28 (for LAMPS sonobuoy data link) for command, control, and communications
- Marconi AN/LN-66 navigation radar on hulls 47-48, replaced with the Raytheon AN/SPS-64(v)9 on subsequent hulls
- SH-60B Seahawk LAMPS III, and SH-2F LAMPS I (CG 47-48) helicopters.

There are no full-scale development start dates in the SARs for the CG 47 class. However, the characteristics of the ship were approved in March 1978. There was no development quantity for the CG 47 class; however, the AEGIS prototype had been extensively tested at sea on board the Norton Sound (AVM-1), and the hull and

propulsion systems had been proven in the DD 963 Spruance class. In spite of this background, development costs were 23 percent greater than originally estimated.

Approval for production was in January 1978, with the first production contract following in September 1978. Initial operational capability was in September 1983, six months ahead of the approved estimate. Production costs for the development estimate quantity were 6 percent less than the original March 1978 estimate.

The following acquisition initiatives have been applied to the CG 47 Ticonderoga class procurement:

- Modification of an existing platform (both hull and propulsion)
- Prototyping and extensive testing of the major subsystem—the AEGIS weapons system
- Design and production under cost plus award fee contracts for hulls 47-53, and under fixed-price incentive contracts for hulls 54-73. The contract for hulls 47-53 represents the first award fee contract by the Navy for a major combatant ship
- Design-to-cost goal established in 1978 and followed through until 1987
- Shipbuilder involvement during contract design "to review the specifications and drawings, familiarize themselves with the (then new) design budget concept (for parallel development of the ship and its combat system), and plan the ship construction in their own yards." [Tibbits and Keane, 1995]. Because the yards were not able to reach consensus in major areas of transition from design to production, NAVSEA had to adopt a "lowest common denominator" approach to design rather than a top-level build strategy
- Independent cost analysis in 1977
- Production competition between Bath Iron Works and Ingalls Shipbuilding
- Dual-sourcing of subsystems.

The CG 47 Ticonderoga class was not subjected to multi-year procurement or total package procurement.

A number of factors could have contributed to the program coming in under planned cost. Although competition was not planned early in the program, a second contractor, Bath Iron Works, was brought on in 1981. The manner in which significant technical upgrades were implemented over the course of the program may also have helped the program stay within its cost plans; these were handled as block upgrades to

minimize disruption. In addition, the program costs include the cost of the Aegis weapon system, a system that had been prototyped and thoroughly tested. The award fee contract and the establishment of a design-to-cost goal may also have been factors.

C. CVN 68 NIMITZ CLASS AIRCRAFT CARRIERS

The CVN 68 Nimitz class ships are nuclear-powered aircraft carriers with the mission to support and operate aircraft, to engage in attacks on targets afloat and ashore, and to engage in sustained operations in support of other forces. These ships are the largest and most complex combatants in the world today. Each has 2 nuclear reactors and nuclear fuel for at least 20 years of normal carrier operations, the equivalent of 11 million barrels of propulsion fuel oil. The Nimitz class carriers require a crew of over 3000, along with 2800 aircrew.

Combat load displacement is approximately 91,478 tons for CVN 68 through CVN 70, 96,386 tons for CVN 71, and 102,000 tons for CVN 72 and CVN 73 [2]. The flight deck area is about 4.5 acres. The ship has four propellers, four aircraft elevators, and four catapults. The ship's main machinery are two GE A4W/A1G nuclear powerplants with four turbines yielding 260,000 hp; and four emergency diesels with 10,720 hp driving through four shafts.

The CVN 68 Class is equipped with:

- Missiles: Three Raytheon GMLS Mk 29 octuple launchers, NATO Sea Sparrow, and semi-active radar homing to 14.6 km at 2.5 Mach.
- Guns: Four General Electric/General Dynamics 20 mm Vulcan Phalanx 6-barreled Mk 15 (3 in CVN 68 and 69).
- Torpedoes: Six 324 mm Mk 32 tubes used for anti-wake homing torpedo countermeasures (being fitted).
- Countermeasures: Decoys: 4 Loral Hycor SRBOC 6-barreled fixed Mk 36; IR flares and chaff to 4 km. SSTDS (torpedo defense system). SLQ 36 Nixie (Phase I).
- ESM/ECM: SLQ-32(V)4 (in DVN 73), SLQ 29 (WLR 8 radar warning and SLQ 17AV jammer and deception system). Being replaced by SLQ-32(V)4.
- Combat Data Systems: NTDS/ACDS naval tactical and advanced combat direction systems; Links 4A, 11 and 14. Link 16 in due course. JOTS, POST,

CVIC, TESS UMM-1(V)1, SSQ-82. SATCOMS SRR-1. WSC-3 (UHF). WSC-6 (SHF). USC-38 (EHF).

- Fire Control: 3 Mk 91 Mod 1 MFCS directors (pat of the NSSMS Mk 57 SAM system).
- Radar: (1) Air search: ITT SPS 48E, 3D, E/F band; Raytheon SPS 49(V)5, C/D band; Hughes Mk 23 TAS, D band. (2) Surface search: Norden SPS 67V, G band. (3) CCA: SPN 41, 2 SPN 42 (CVN 68-70), SPN 43B, SPN 44, 2 SPN46 (CVN 71-73), J/K/E/F band. (4) Navigation: Raytheon SPS 64(v)9, Furuno 900, I/J band.
- Fixed Wing Aircraft: Transitional air wing includes: 20 F14 Tomcat, 20 F/A-18 Hornet, 4 EA-6B Prowler, 6 S-3A/B Viking. The Navy's Power Projection airwing adds 4 more Hornets. The so-called "50 TACAIR airwing" adds 12 Hornets and 2 Vikings, and removes 14 Tomcat and all Intruders.
- Helicopters: 8 SH-3G/H Sea King or SH-60F Seahawk.

Because carriers are so large and the building cycle is so long, we have grouped the carriers into three programs—CVNs 68-70, CVNs 71-73, and CVNs 74-76. All have been built by Newport News Shipbuilding, the only US shipyard with the appropriate capability. The costs of nuclear propulsion plants, developed jointly by the Department of Energy and DoD and provided as GFE, are not included here. All three of the programs used contract incentives in production.

The first ship in the class, the Nimitz (CVN 68), was authorized in FY 1967 and commissioned in May 1975. The final ship in this group, the Carl Vinson, was commissioned in March 1982. The first group of carriers had the highest cost growth, 17 percent, of any of the carrier groups. This may have been due to the magnitude of the technical advance from the Enterprise. Lead time for procurement of nuclear propulsion plant components is more than 2 years longer than the next most limiting hardware.

The Theodore Roosevelt (CVN 71), the first ship in the second group of carriers, was authorized in FY 1980 and commissioned in October 1986, a year earlier than planned. The initial contract for CVN 71 was unpriced and essentially extended the terms of the CVN 70 contract. Later, the contract was amended to a fixed-price-incentive-fee type that provided incentives to deliver the carrier as early as possible. The contract for CVN 72 and CVN 73 was awarded in December 1982. The last carrier in the group,

George Washington (CVN 73) was commissioned in July 1992. Schedule growth was 8 percent, and cost growth was only 1 percent.

In the final group, the John C. Stennis (CVN 74) and the Harry S Truman (CVN 75) were contracted for in June 1988. The Stennis was scheduled to be commissioned in December 1995, and the Truman is planned for July 1998. The Ronald Reagan (CVN 76) was the first major warship design of the 1990s, a modified-repeat design. As will be discussed later, the shipbuilder and other major stakeholders participated in the design from the earliest stages. [2] The carrier is scheduled to be commissioned in December 2002. Cost growth has been about 8 percent so far.

D. DD 963 SPRUANCE CLASS DESTROYERS

The primary missions of the DD 963 Spruance class destroyers are antisubmarine and antisurface warfare, as part of an aircraft carrier or surface task force, and escort and shore bombardment support for an amphibious task force. The DD 963 class were built under a total package procurement contract by the Ingalls Shipbuilding Division of Litton Industries in a new shipyard at Pascagoula, which was specifically designed and tailored for the class as part of the TPP competition. This propulsion plant underwent extensive prototyping both ashore and afloat and has since become the baseline plant for all of the Navy's subsequent gas-turbine powered ships. The DD 963 has four General Electric LM2500 gas turbines on two shafts with controllable, reversible pitch propellers. The DD 963 class has hanger space for two SH-60B LAMPS helicopters. The MK 41 vertical launch system is being retrofitted to all but hulls 974, 976, 979, 983, 984, 989, and 990, for launch of the General Dynamics RIM-66 Standard Missile 2–Medium Range for antiair warfare, the McDonnell Douglas RGM-84 Harpoon cruise missile for antisurface warfare, the General Dynamics BGM-109 Tomahawk cruise missile for strikes against ship and land targets, and the Honeywell RUR-5A antisubmarine rocket for antisubmarine warfare.

For antisubmarine warfare, the DD 963 class is equipped with the:

- General Electric/Hughes AN/SQS-53A/B hull-mounted active and passive sonar, which is being upgraded to the General Electric AN/SQS-53C
- General Electric AN/SQR-19 TACTAS passive towed array sonar, which is being upgraded to the Gould AN/SQQ-89(v)6
- Singer-Librascope MK 116 antisubmarine warfare fire control system
- MK 32 torpedo launcher

- Aerojet-General MK 46 or Honeywell MK 50 torpedo.

For antiair warfare, the DD 963 class is equipped with the:

- Lockheed AN/SPS-40B/C/D air search radar on hulls 963-996, and Raytheon AN/SPS-49V on hull 997
- Raytheon Sea-Sparrow launcher MK 29 for RIM-7 missiles
- General Dynamics MK 15 Phalanx close-in weapon system.

For antisurface warfare and strikes against land targets, the DD 963 class is equipped with the:

- Active radar/anti-radiation homing to 460 km
- FMC 5-inch/54 MK 45 gun
- ISC Cardion AN/SPS-55 surface search radar
- Lockheed AN/SPG-60 gun tracking and illuminator radar
- Lockheed AN/SPQ-9A or Raytheon MK 91 surface search weapons control radar
- Lockheed Electronics Company MK 86 gun fire control system
- McDonnell Douglas RGM-84 Harpoon antiship missile.

The DD 963 class is also equipped with the:

- Raytheon AN/SLQ-32(v)2 for electronic warfare
- Hughes Aircaft Navy Tactical Data System links 11 and 14, SATCOMS SRR-1, WSC-3(UHF), USC-38 (EHF) (in some), SQQ 28 (for LAMPS data link) for command, control, and communications
- Raytheon AN/SPS-64(v) radar for navigation.

The DD 963 Spruance class was procured to replace World War II destroyers, which were facing block obsolescence. The DD 963 class differs from its predecessors in a number of ways. It was the first U.S. combatant to have gas turbine propulsion and controllable, reversible pitch propellers. It was the second total package procurement for a ship program, following the LHA program by one year. The same contractor, the Ingalls Shipbuilding Division of Litton Industries, was responsible for both design and construction of the DD 963 (and the LHA as well). The contractor was given great leeway in designing the ship to meet broad performance and physical requirements, with minimal detailed design guidance from the Navy. The ships were the first to be built in a new, and

for that time, revolutionary shipyard using land level erection and modular construction techniques. Many of the design and engineering personnel were from the aerospace industry, and they brought to the program an emphasis on systems analysis techniques, together with other aircraft construction techniques such as modular construction, kitting, early outfitting and land level transport of major components.

Engineering development commenced in June 1970. The gas turbine propulsion system had previously been prototyped and tested extensively both at a land-based engineering facility near Philadelphia and subsequently at sea in a cargo ship. The controllable pitch propeller had been prototyped and tested at sea on the Patterson (FF 1061) and Barbey (FF 1088). The combat information system was prototyped at Litton Industries facilities in Culver City. Production started in June 1972, 7 months ahead of schedule. The initial operational capability was 5 years later, 2 years behind schedule.

A small part (less than 2 percent) of the total package procurement cost was paid for out of development appropriations, and that amount was 6.4 percent greater than what had originally been estimated. The total production costs of $2,649.9 million in fiscal year 1970 constant dollars shown in the latest available SAR (December 1978), do not include the costs for the settlement of the cost overrun negotiations between the Navy and Litton Industries. As a result of that settlement, production costs were increased by approximately $354 million in 1970 constant dollars, to obtain a revised estimate for total production costs for the 31 ships of the DD 963 class of $3,004.3 million in 1970 constant dollars, as shown in Table A-1.

Table A-1. DD 963 Production Cost Calculation

	1970 Dollars
Production costs in 1278 SAR	2,650
Settlement:	
+ Economic changes	244
+ Contract cost overrun	184
+ Other cost overrun	1
+ PL 85-804 contract settlement	64
- Costs already included in 12/78 SAR	-139
Production costs for 31 ships	3,004
- Contract cost of 31st ship	-82
Production costs for the 30 ships of the development estimate	2,922

The total production costs for the first 30 ships of the original quantity was obtained simply by subtracting the incremental contract cost for the 31st ship of $82.1 million 1970 constant dollars. Using that total production cost of $2,922 in 1970 constant dollars for the first 30 ships, production costs increased by 23 percent over what was originally estimated.

After the contract for the first thirty ships, four additional Spruance class ships were ordered for the Iranian navy, with an enhanced antiair warfare capability. Because of the overthrow of the Shah, Iran never took delivery of these ships, and they became the DD 993 Kidd class (often referred to as the Ayatollah class). A thirty-first Spruance class ship, DD 996, was also authorized and subsequently completed.

The following acquisition initiatives have been applied to the DD 963 Spruance class procurement:

- A competitive advanced development was held
- The propulsion system and the combat information system were prototyped, and the propulsion system was extensively tested both ashore and at sea
- The first 30 ships were procured under a multi-year total package procurement with a fixed price incentive contract covering both development and production.

The DD 963 class has been an operational success, but the program was a financial disaster. During the same time that Litton Industries was building the DD 963, it had a total package procurement contract for the LHA. These two programs almost bankrupted Litton Industries and went a long way toward discrediting the procurement policies and management capabilities of the Navy.

E. DDG 51 ARLEIGH BURKE CLASS DESTROYERS

The primary missions of the DDG 51 class destroyers are antiair, antisubmarine, and antisurface warfare, as part of an aircraft carrier or surface task force. It is the Navy's second class of AEGIS-equipped ships, and was originally conceived to be a less costly supplement to the CG 47 Ticonderoga class. It was designed by the Navy, and the detailed design and construction are being done jointly by the Bath Iron Works and the Ingalls Shipbuilding Division of Litton Industries.

The DDG 51 class has four General Electric LM2500 gas turbines on two shafts with controllable, reversible pitch propellers, a direct derivative of to the propulsion systems of the DD 963 and CG 47 classes. The DDG 51 class does not have a helicopter hanger, but will have the capability of landing and refueling SH-60B LAMPS helicopters. The DDG 51 class is equipped with the MK 41 vertical launch system, for launch of the General Dynamics RIM-66 Standard Missile 2–Medium Range, the McDonnell Douglas RGM-84 Harpoon cruise missile, the General Dynamics BGM-109 Tomahawk cruise missile, and the Honeywell RUR-5A antisubmarine rocket MK 16 torpedo/missile.

For antiair warfare, the DDG 51 class is equipped with the:

- General Electric RCA Government Systems Division AEGIS air defense system with the AN/SPY-1D phased array radar
- Raytheon/RCA AN/SPG-62 missile fire control radars
- General Dynamics MK 15 Phalanx close-in weapon system.

For antisubmarine warfare, the DDG 51 class is equipped with the:

- Gould AN/SQQ-89 sonar system, consisting of the AN/SQS-53C hull-mounted active and passive sonar, the AN/SQR-19 TACTAS towed passive sonar array, and the AN/SQR-4 LAMPS-III terminal
- Aerojet-General MK 46 or Honeywell MK 50 torpedo.

For antisurface warfare, the DDG 51 class is equipped with the:

- FMC 5-inch/54 MK 45 MOD 1 gun
- Norden AN/SPS-67 surface search radar
- MK 160 gunfire control system;

The DDG 51 class is also equipped with the:

- Raytheon AN/SLQ-32(v)2 in hulls 51-58, and AN/SLQ-32(v)3 in subsequent hulls, for electronic warfare
- Hughes Aircraft Navy Tactical Data System MOD 5 with links 4A, 11, 14, and 16, for command, control, and communications
- Raytheon AN/SPS-64(v)9 radar for navigation.

The DDG 51 class differs from its immediate predecessors, the DD 963 and CG 47 classes, in several ways. It has a wider beam, for more kindly sea-keeping in heavy seas. The shape of the hull, superstructure, and top-hamper is designed to minimize radar

returns. Steel is used in the deckhouse in place of aluminum in order to reduce the fire hazard.

Detailed design and construction of the DDG 51 class was authorized in December 1983; however, the production contract was not awarded until April 1985. Production started October 1986, two months behind schedule. Initial operational capability was achieved February 1993, 28 months behind schedule.

The program had a true development estimate baseline, instead of the production estimate common to many of the ship programs. The current estimate for development costs is 133 percent greater than the development estimate. Production costs for the originally estimated quantity of 18 are expected to be approximately 1 percent less than originally expected.

The following acquisition initiatives have been applied to the DDG 51 Arleigh Burke class procurement:

- Use of modified subsystems from previous ship classes with extensive operational experience
- Design-to-cost goals established early and maintained
- Dual-source production competition with fixed-price incentive contracts
- Competitive multi-year procurement planned for fiscal year periods 1990-91 and 1992-94, with fixed-price incentive contracts
- Procurement streamlining with each buy.

F. FFG 7 OLIVER HAZARD PERRY CLASS FRIGATE

The Oliver Hazard Perry class frigates were developed as “low-end” ships with limited capabilities. The mission of the FFG 7 class was to protect underway replenishment groups, amphibious forces, and military shipping from submarine, air, and surface threats. The FFG 7 was an in-house Navy design with Bath Iron Works serving as the lead yard for detail design and construction of the first ship. Subsequent ships were produced at the Bath Iron Works, Todd Seattle, and Todd San Pedro shipyards for the United States and Australia. It has also been produced in Australia, Spain, and Taiwan for the navies of those nations. It has two General Electric LM-2500 gas turbines driving a single shaft with a controllable, reversible pitch propeller—basically one-half of the propulsion system that had received extensive operational use in the DD 963 Spruance

class. It is equipped with one FMC MK 13 Mod 4 missile launch system for launching the General Dynamics RIM-66 Standard Missile 1–Medium Range for antiair warfare, and the McDonnell Douglas RGM-84 Harpoon for antisurface warfare. It has a hanger for the LAMPS helicopter and a helicopter landing system.

For antiair warfare, the FFG 7 class is equipped with the:

- Raytheon AN/SPS-49(v)4/5 air search radar
- General Dynamics Phalanx close-in weapon system
- Sperry MK 92 Mod 2 (Mod 6 on hull 61) fire control system
- FMC Mk 13 Mod 4 missile launch system.

For antisubmarine warfare, the FFG 7 class is equipped with the:

- Gould AN/SQQ-89(v)2 sonar system, consisting of the AN/SQS-53B hull-mounted active and passive sonar, and the AN/SQR-19 TACTAS towed passive sonar array, originally fitted on hulls 8 and 36-61, and being retrofitted on all others, which were originally equipped with the Raytheon AN/SQS-56 hull-mounted active and passive sonar
- MK 309 torpedo fire control system
- MK 32 torpedo launcher
- Aerojet-General MK 46 or Honeywell MK 50 torpedo.

For antisurface warfare, the FFG 7 class is equipped with the:

- ISC Cardion AN/SPS-55 surface search radar
- Oto-Melera 3-inch (76mm)/62 MK 75 gun.

The FFG 7 class is also equipped with the:

- Raytheon AN/SLQ-32(v)2, for electronic warfare
- Hughes Aircraft Navy Tactical Data System with Links 11 and 14, for command, control, and communications.

Engineering development started in October 1972. Before that, most of the major systems had already been developed and were in use on other ship classes. The controllable, reversible pitch propeller had been prototyped and tested on the Patterson (FF 1061) and Barbey (FF 1088) and was the same as that installed on the DD 963 class. The AN/SQS-56 sonar had been prototyped and tested on the DD 840. In spite of this, development costs were 43 percent greater than originally expected.

The production contract was awarded in October 1973, 4 months behind schedule. Production was authorized in December 1975, nine months behind schedule. Initial operational capability was attained in March 1979, 21 months behind schedule. The production span was reduced from an originally expected 135 months to 131 months, with an increase of only one in the quantity produced. Production costs were 59 percent greater than originally expected.

The following acquisition initiatives have been applied to the FFG 7 Oliver Hazard Perry class procurement:

- Prototyping of the propulsion and sonar systems
- Extensive use of modified subsystems from other ship classes
- Design-to-cost in 1971-1981
- Independent cost analyses in 1976 and 1976
- Independent test
- Competitive ship construction in three different shipyards
- Cost plus fixed fee, and cost plus incentive fee contracts for full-scale development and lead ship construction
- Fixed-price incentive contracts for subsequent production.

Notably for a program of this size during that time period, neither total package procurement nor multi-year procurement were used.

Many things were done "right" for this program—extensive use of subsystems and prototyping of subsystems have generally been associated with success in other ships and in other types of programs. Nevertheless, the FFG 7 had very high cost growth. This may have been due to the complex acquisition plan involving three yards and the consequent early breakdown in communications among the yards, the single lead ship designer, and the Navy management office. Although unquantifiable, it can also be inferred that a major contributor to the cost growth was the unanticipated double-digit inflation in the economy of the time. The government attempted to insulate the shipyards from the risks of inflation with standard escalation clauses but this was soon overrun by almost daily changes in inflation rates. The same effect was noted in the LHA and the DD 963 contracts although the peculiarities of TPP masked the effects of inflation on those programs.

G. LANDING CRAFT, AIR CUSHION (LCAC)

The LCAC transports weapon systems, equipment, cargo, and personnel of the assault elements of the Marine air/ground task force from ship to shore and across the beach. The LCAC is a fully amphibious air cushion vehicle capable of operating from existing and future amphibious well deck ships.

In 1970, the first contracts for design and construction of two prototype Amphibious Assault Landing Crafts (AALC) called Jeff Craft A and Jeff Craft B were awarded to Aerojet General and Bell Aerospace. The two prototypes were delivered in 1978 and 1979. After extensive testing of the two prototypes, Bell Aerospace was competitively selected and awarded a contract for the follow-on LCAC production program of six craft (three in FY82 and three in FY83). In November 1983 Bell was awarded a contract for long lead material, and in March 1984 a construction contract for six additional LCACs.

The first LCAC successfully completed Acceptance Trials in December 1984. The initial phase of OT-IIIA in early 1985 showed discrepancies affecting craft reliability, and correction was made during OT-IIIB in April 1987. Full production was approved by the Assistant Secretary of the Navy in June 1987. A second source, Avondale Gulfport Marine (AGM), formerly Lockheed Shipbuilding Co., was selected to build 2 FY85 craft in September 1985. Production contracts have since been awarded for the balance of the planned fleet.

The acquisition initiatives applied to the LCAC program include:

- Prototyping before Milestone II
- Dual sourcing in both development and production
- Design-to-cost
- Multi-year procurement
- Incentive contracts in production. Originally CPAF, the contracts were converted to CPIF with a logistics support award fee. Since FY91, Textron has been the only builder, on a FPAF basis. There has been a performance award fee since FY 91.

The current plan calls for a quantity increase of more than 50 percent, to 91 craft.

Both development and production cost growth were substantial, although the program reached IOC almost on time. Development cost growth was 56 percent, and production cost growth was 28 percent.

H LHA 1 TARAWA CLASS AMPHIBIOUS ASSAULT SHIP

The primary mission of the LHA 1 class amphibious assault ship is to transport Marine helicopters and combat personnel with their equipment, and provide a platform for helicopter operations during amphibious assaults. The class has a well dock, which can be flooded, for use in off-loading personnel and equipment into landing craft. Because the LHA was intended to travel in accompaniment with a major task group, the ships had no defense capabilities against submarine threats, and minimal capabilities against surface and air threats. The LHA 1 class has two Combustion Engineering boilers and two Westinghouse geared turbines driving twin propulsion shafts. The program was awarded to the Ingalls Shipbuilding Division of Litton Industries, in their Pascagoula shipyard as the first of the TPP ship contracts.

For defense against air and surface threats, the LHA 1 class is equipped with the:

- Lockheed AN/SPS-40B/C/D air search radar
- Hughes AN/SPS-52C air search radar
- Raytheon AN/SPS-67 surface search radar
- Lockheed AN/SPG-60 fire control system
- Lockheed AN/SPQ-91 fire control system
- FMC 5-inch/54 MOD 1 gun
- General Dynamics MK 15 Phalanx close-in weapon system
- McDonnell Douglas MK 242 25-mm automatic cannon.

The LHA 1 class is also equipped with the:

- Raytheon AN/SLQ-32v(3) for electronic warfare
- Motorola AN/SSR-1 satellite communications system
- Raytheon AN/SPS-64(v)9 navigation radar.

The LHA 1 class was conceived to replace multiple World War II designs such as the LSD, AKA, and APA. Originally called the large general purpose amphibious assault ship, the LHA incorporated the overall capabilities of these earlier designs. However, it is

larger, faster and carries more helicopters and landing craft than any of its predecessors. It is capable of carrying 1,500 combat-equipped Marines and putting them ashore on a contested beach or landing site. The LHA also has a small hospital to care for casualties.

The baseline for the program was in DCP #29 dated December 1968 and called for 9 ships at $159 million each. Development of the LHA 1 class was authorized in April 1969 and was competitively awarded to the Ingalls Shipbuilding Division of Litton Industries with a fixed-price incentive contract for a total package procurement. Costs allocated to the development appropriation were very slightly (less than 0.5 percent) less than originally expected.

By December 1970, the quantity was cut back by contract change, from 9 ships to 5, and planned unit cost increased to $197 million. The increase is primarily attributed to cancellation charges ($110 million) and increased escalation costs which were reflective of the double digit inflation cited previously. No explanation was given for the cutback, although it may have been driven by political factors..

Production started in January 1971, three months behind the originally scheduled date. That same year, there was a one-month work stoppage in the new Litton shipyard at Pascagoula. Litton farmed out 44 hull steel assemblies for fabrication to Ingalls Nuclear Shipbuilding in Pascagoula, Mississippi. In response to further start-up problems and management disorders, and under pressure from the Navy, in July 1972, the contractor merged the two yards (Ingalls Nuclear Shipbuilding and Litton Ship Systems) into a single organization, Ingalls Shipbuilding. While the merger improved both management control and labor availability, an inadequate number of skilled workers contributed to schedule problems as the workforce swelled from 8,000 to a peak of 21,000 during the high point of the combined LHA and DD 963 programs. In addition, there was a 31-day strike in December 1974.

LHA 1 was delivered in May 1976. In June 1976, Ingalls Shipbuilding stopped work because their expenses were greatly exceeding the progress payments under the contract, creating serious cash flow problems for Litton Industries and the potential for a huge cost over-run, which they would have to absorb. Following a series of legal actions by both the Navy and Litton Industries, a preliminary injunction was issued that forced Litton Industries to continue working and forced the Navy to pay 91 percent of the actual costs incurred by Litton while the injunction remained in effect. By May 1977, Navy payments under the injunction exceeded the contract value. The injunction was extended,

and in June 1978, an agreement was finally reached between the Navy and Litton Industries for both the DD 963 Spruance class and LHA 1 Tarawa class programs, under which the target prices for both programs were increased by a total of approximately $447 million, leaving Litton Industries with a loss of over $200 million on the two programs. Production costs for the quantity estimated at the start of development were 51 percent greater than the cost estimate made at the start of development.

Initial operational capability was attained in May 1977, 39 months behind schedule. The production quantity was decreased from nine to five, and production ended five years later than originally expected.

Only limited information was available to show the acquisition initiatives that were applied to the LHA 1 Tarawa class procurement. The SARs showed that the following initiatives were used:

- Competitive advanced development
- Total package procurement with multi-year awards
- Fixed-price incentive contract to cover both development and production.

In addition, these innovative programs were incident to the TPP concept:

- Prototyping of major subsystems
- Modular construction
- Early outfit of modules and units
- Land level construction and material handling.

I. LHD 1 WASP CLASS AMPHIBIOUS ASSAULT SHIP

The primary mission of the LHD 1 class amphibious assault ship is to transport Marine helicopters and combat personnel with their equipment, and provide a platform for helicopter operations during amphibious assaults. A hospital is provided for the care of combat casualties. The class is a modification of the LHA 1 Tarawa class with identical hull, propulsion, and a well dock that can be flooded for off-loading landing craft. As a major improvement over the LHA, the LHD 1 class is designed to carry 6-8 AV-8B Harriers or up to 20 in a secondary role. The LHD class is now being built by the Ingalls Shipbuilding Division of Litton Industries, in their Pascagoula shipyard.

To support Marine amphibious operations, the LHD 1 class is equipped with the:

- Integrated Tactical Amphibious Warfare Data System (ITAWDS)
- Marine Tactical Amphibious Command and Control System (MTACCS) with links 4A and 11, with links 14 and 16 to be added later.

For defense against air and surface threats, the LHD 1 class is equipped with the:

- Hughes AN/SPS-52C air search radar on LHD 1, and ITT AN/SPS-48E air search radar on subsequent hulls
- Raytheon AN/SPS-49(v)9 air search radar
- Hughes MK 23 target acquisition system radar
- Norden AN/SPS-67 surface search radar
- Raytheon MK 29 guided missile launch system for the Raytheon RGM-7 Sea Sparrow for antiair warfare
- General Dynamics MK 15 Phalanx close-in weapon system.

The LHD 1 class is also equipped with the:

- Raytheon AN/SLQ-32(v)3 for electronic warfare
- Motorola AN/SSR-1 satellite communications system
- Raytheon AN/SPS-64(v)9 navigation radar.

The LHD 1 class provided the additional lift required by the Marines Corps' increasing emphasis on helicopter assault, which was being constrained by the shortfall caused by the cancellation of the last four of the LHA 1 Tarawa class.

The LHD 1 program began in 1981. Initially, it was intended to be a new design program with authorization for the lead ship in 1987. In the spring of 1981, the Navy accelerated the LHD prog by moving the lead ship authorization from 1987 to 1985. Development of the LHD 1 class was authorized in July 1982. In Nov 1985, the Secretary of the Navy directed that the program be further accelerated in a 1984 authorization as a modified LHA design.

The baseline design was completed in June 1982, and the contract design was completed in Nov 83. The detailed design and construction contract was awarded to Ingalls in February 1984 for the lead ship. At construction contract award in February 84, Ingalls was awarded a FPI contract for the lead ship at a target price of $962M. This LHD 1 ship had been estimated to cost $989M by NAVSEA and $1,032M by NCA/OP-96 for

the CAIG review in Sept 1982. Actual construction started in July 1984, 2 months earlier than originally planned.

A competitive contract for the follow ship (LHD 2), with an option to buy 2 more ships (LHD 3 and 4), was awarded to ISI in September 1986. The followship LHD 2 had been estimated to cost $886M by NAVSEA , $856M by NCA for the Aug 85 CAIG review, was awarded (FPI) in Sep 86 to Ingalls at a target price of $401M. This very low award was based on Ingalls drastically reduced labor estimate to build this second ship. This led to a budget reduction in the program to the contract ceiling price of $453M for the LHD 2, and also reduction for the two option ships LHD 3 and 4. A competitive contract for LHD 5 with unevaluated and undefinitized options for LHD 6 and 7 was awarded to ISI in December 1991.

Development costs were 9 percent greater than originally estimated. Production started in February 1984, two months behind schedule. Initial operational capability was attained in October 1990, six months behind schedule. Production costs for the originally specified quantity were 9 percent less than originally estimated.

The following acquisition initiatives have been applied to the LHD 1 Wasp class procurement:

- Modification of an existing ship type, the LHA 1 Tarawa class
- Extensive use of previously developed systems from other ships
- Design-to-cost from June 1982 through February 1984
- Independent cost analysis in August 1982 and August 1987
- Procurement streamlining with each buy
- Non-competitive cost plus award fee contracts for full-scale development
- Sole-source, fixed-price incentive production contract for LHD 1, followed by competitive multi-year, fixed-price incentive procurement contract for hulls 2-4 in 1986. Hulls 1-4 had an incentive fee for logistics support due to problems in that area. After that, the Navy used an incentive fee strategy. LHD 5 had $15 million in incentives available, while LHD 6 had $10 million available. Schedule, cost, and quantity were incentivized.

J. LPD 17 CLASS AMPHIBIOUS TRANSPORT DOCK

The LPD 17 program is not far along enough to be included in the analysis of acquisition outcomes, but we can provide a brief discussion of the ship's features and acquisition strategy. The LPD 17 is a new amphibious transport dock assault ship. "A notional build strategy was developed during preliminary design, keyed to a "virtual shipyard," to aid the designers in addressing producibility from the start of design...During contract design, five competitively selected shipbuilders were brought onboard to help review the specifications, develop additional producibility improvements, comment on the implication of metrication and CALS... ." [Tibbets and Keane, 1995] Milestone 0 was in November 1990, and Milestone I was in January 1993. Contract award between competing teams is expected by late FY96.

K. LSD 41 WHIDBEY ISLAND CLASS LANDING SHIP DOCK

The mission of the LSD 41 Whidbey Island Class is to transport and offload Marines and their equipment into landing craft during an amphibious assault. It provides limited docking and repair services for conventional landing craft and air cushion landing craft. Designed to travel as part of a task force, the LSD 41 class has no capabilities for defense against submarines, and very limited capabilities for defense against air or surface threats. It is a modification of the LSD 36 Anchorage class, with four commercial Colt-Pielstick 16PC25-v400 diesels driving two shafts with controllable pitch propellers.

The LSD 41 class proceeded routinely through Navy preliminary and contract design with detail design and lead ship construction awarded to Lockheed Shipbuilding and Construction. Follow-on ships have been built by Lockheed Shipbuilding and Construction, and Avondale Shipyards.

For defense against air and surface threats, the LSD 41 class is equipped with the:

- Raytheon AN/SPS-49 air search radar
- Norden AN/SPS-67 surface search radar
- General Dynamics MK 15 Phalanx close-in weapon system on hulls 41-46, replaced by the McDonnell Douglas MK 88 25-mm Bushmaster gun on hulls 47 and 48.

The LSD 41 class is also equipped with the:

- Raytheon AN/SLQ-32(v)1 for electronic warfare

- Motorola AN/SSR-1 satellite communications system
- Raytheon AN/SPS-64(v)9 navigation radar.

The LSD 41 class was planned to offset the shortfall in amphibious lift created by the retirement of the Thomaston (LSD 28) class. After extensive design and engineering review by the Navy, Colt-Pielstik diesel engines were selected to reduce crew size and engine room maintenance requirements. The engines were first prototyped at a land-based test site in Philadelphia and represent the Navy's introduction to medium-speed diesels.

The requirement for the LSD 41 was established in November 1976. Development of the LSD 41 class was authorized in November 1978. Development costs were 11 percent greater than had been originally estimated. Production started in January 1981 with a contract to Lockheed for the lead ship. Contracts for the first two follow-up ships were awarded to Lockheed in March 1982 and January 1983. In November 1983, Avondale won a competitive award for hull 44, with options for hulls 45-48. Initial operational capability was attained in February 1986, three months behind schedule. The LSD 41 demonstrated that it met its performance goals in December 1984.

The program was baselined very late in the process (April 1981) more than 3 years after Milestone II and 3 months after the lead ship contract was awarded. Production costs for the originally specified quantity were 10 percent lower than estimated.

The following acquisition initiatives have been applied to the LSD 41 Whidbey Island class procurement:

- Use of a commercially developed diesel engine that has been widely used in merchant shipping
- Extensive use of subsystems already in use on the LSD 36 Anchorage class
- Full-scale development competition
- Design-to-cost, from June 1982 to February 1984
- Independent cost evaluation
- System production competition between Lockheed and Avondale
- Cost plus award fee contract for lead ship design and construction, later converted to cost plus fixed fee with ceiling, limiting the Government's liability for the overrun to $38 million
- Cost plus award fee contract for the first follow-up ship, later converted to fixed-price incentive contract with a 50/50 share ratio

- Fixed-price incentive contract for the second follow-up ship
- Competitively awarded contract for hull 44 with options for hulls 45-48
- Fixed-price incentive contracts for hulls 44-48 that were later converted to firm fixed-price contracts
- Logistics award fees for hulls 49-51
- A broader performance fee on the order of $4 million for hull 52.

L. LSD 41 CV HARPERS FERRY CLASS LANDING SHIP DOCK

The LSD 41 CV (cargo variant) Harpers Ferry class is a modification of the LSD 41 Whidbey Island class, with a smaller well dock to accommodate a greater volume of cargo. The mission and the equipment are the same as for the LSD 41 Whidbey Island class. The ships are being built by Avondale Shipyards, the follow yard for the LSD 41.

Development of the LSD 41 cargo version was authorized in December 1987. Actual development costs were 28 percent below the original estimate. Production started in November 1989, four months behind schedule. Initial operational capability currently estimated to be 7 months behind schedule. Production costs for the originally specified quantity are currently estimated to be 5 percent less than originally estimated. However, it is believed that the contractor lost money on the contracts.

The following acquisition initiatives have been applied to the LSD 41 cargo version Harpers Ferry class procurement:

- Modification of an already in-use design, with all systems demonstrated on the LSD 41 Whidbey Island class
- Design-to-cost in 1986, although there was no approved design-to-cost goal by 1987
- Independent cost evaluation in 1987
- Production competition between Avondale and Lockheed for multi-year, fixed-price incentive contract.

M. MCM 1 AVENGER CLASS MINE COUNTERMEASURE SHIP

The MCM 1 Avenger Class is a mine countermeasure ship. In June 1979 several alternative program approaches were evaluated in replacing the aging MSO 422/508 ocean minesweeper fleet. This tradeoff analysis, completed in March 1980, was

accomplished in lieu of a preliminary design effort. During the latter portion of the contract design effort, 2 ship system design support contractors, one designated primary, the other secondary, were selected to participate in the ship design effort.

The primary SSDS contractor, Peterson Builder, was awarded the contract for detail design and construction of the lead ship MCM1 (Avenger). Marinette Marine Corp. was selected as the follow yard and awarded MCM 2 in May 83. The construction contracts are firm fixed price with options.

All ships of this class have been delivered; the final one in July 1994. Some technical performance in ships 3-12 (intermittent failures of the diesel engines used for propulsion and to power the ship's service generator) have been resolved. Upgraded engines have been installed on all MCMs using Isotta Fraschini engines (MCMs 3-14).

We would expect to see little cost growth, since the baseline was done after the lead ship delivery. The development cost growth figure is not meaningful, since all development costs had been incurred when the program baseline was done. There was only 4 percent cost growth in production.

N. MHC 51 OSPREY CLASS COASTAL MINE HUNTER

The MHC is a 57.2-meter long glass-reinforced-plastic hull ship with low magnetic-signature equipment, diesel engines, and cycloidal propulsion. Major payload equipments include advanced minehunting sonar, and modularly deployed either an AN/SLQ-48 mineneutralization system or a mechanical minesweeping system. The MHC ship serves as the "low-mix" complement to the ocean going Mine Countermeasure (MCM) ship. The MHC was initiated in 1986. It is based on the LERICI Class Minesweepers designed and built by Inter-marine S.p.A. (IMSpA), an Italian shipbuilder. IMSpA was awarded a design contract to modify the LERICI design to meet U.S. Navy operational requirements. The company had already built the ship for three countries. The design had a large fiberglass hull, with machinery suspended from above, not bolted to the hull. Under shock, the hull was found to flex. Moreover, the Italian company teamed with Hercules, a missile company, to try to start up a U.S. shipyard from scratch.

Milestone I (authorization for contract design) was approved in June 1986. Milestone II (leadship production authorization) was issued December 1986.

There was a sole source award of the lead ship MHC contract to Intermarine USA (IMUSA) with a requirement to competitively select a second source shipbuilder. The lead ship (MHC 51) contract was awarded to IMUSA in May 1987. The follow ship MHC 53 was awarded to Avondale Industries Inc. in October 1989. Full rate production (Milestone IIIB) was authorized January 1990. The current MHC procurement level is 12 ships. All ships are currently under contract.

The MHC 51 coastal minehunter ship program is a fairly rapid program. A production estimate dated March 1992 is the only available baseline and was included in the December 1991 SAR. The lead ship was delivered December 1992. The class lead ship, MHC 51 (USS OSPREY) was delivered August 1993.

The development costs were negligible and were 8 percent over plan. Production costs were 1 percent over plan.

O. SURTASS/T-AGOS 1 STALWART CLASS OCEAN SURVEILLANCE SHIPS

The SURTASS/T-AGOS 1 system consists of UQQ-2 Surveillance Towed Array Sonar System (SURTASS) mounted on T-AGOS 1 Stalwart class ships. The UQQ-2 SURTASS subsystem has been selected for purchase by Japan. The system is used for detecting submarines in oceanic areas where fixed underwater arrays are not available. The array is reeled out from the stern of the ship to a depth below the convergence layer, and towed at a speed of approximately 3 knots. Signals from the sensors on the array are transmitted back up the array to the ship, where they are transmitted via satellite to a shore-based processing facility. The ship design was modified from the design of a commercial off-shore oil-drilling rig support ship, with twin shafts driven by two 1,600-horsepower electric motors drawing power from four Caterpillar 398 diesel generators. Diesel-electric power was chosen to minimize the amount of own-ship's noise during surveillance operations, but also provides enough power to allow transit speeds of up to 16 knots. A 550-horsepower bow thruster is provided for maneuvering.

Development started in October 1974, and initial operational capability was to have been attained in August 1983. It was not achieved until September 1984. A prototype of the towed array was built and tested on a Navy research ship operated by the University of Hawaii. Numerous technical problems in developing the towed array are reflected in a development cost growth of 239 percent over the approved estimate.

Production began in September 1980, over 3 years behind the date estimated at the start of development.

A multi-year production contract for the first twelve ships was awarded to Tacoma Boat, which went bankrupt before ships 9 through 12 were completed. Halter Marine was subsequently awarded a contract for ships 13 through 18. Production costs for the quantity estimated at the start of development were 64 percent greater than the cost estimate made at the start of development. Because of problems with the sea-keeping characteristics of the T-AGOS 1 during 3-knot towing operations in heavy seas, a twin-hulled SWATH design was built by McDermott Marine for four ships in the T-AGOS 19 Victorious class. The ships built by McDermott have grown considerably in cost.

The following acquisition initiatives have been applied to the SURTASS/T-AGOS procurement:

- A prototype of the UQQ-2 SURTASS was developed and tested—but no prototype of the ship, which could have been a charter of a commercial vessel, was tested to see if the sea-keeping characteristics were satisfactory in heavy seas
- There was competitive full-scale development at the subsystem (sensor) level among four companies during 1974-5
- Design-to-cost was applied to the ship
- An independent cost estimate was made in 1974
- Multi-year procurement was applied to the development contract for the ship during 1976-80
- A total package procurement contract was awarded for the production of the first twelve ships in 1980, but this was changed to a cost plus fixed fee for 1981-90
- Production of the UQQ-2 was sole-sourced, and a firm fixed-price production contract for ships 13 through 19 was competitively awarded.

The ships have been operated by contractors since 1985 following a privatization study.

In a later program, T-AGOS 23 class ships are planned to be used for worldwide ocean surveillance. They carry underwater listening devices to collect information that is passed to analysts on shore through electronic equipment on board the ships. The T-AGOS 23 program has had many problems, and the ships have not been built.

P. T-AO 187 HENRY J. KAISER CLASS REPLENISHMENT OILERS

The mission of the TAO 187 Henry J. Kaiser class of replenishment oilers is to:

- Deliver bulk petroleum products from shore depots to surface combatants and AOE, AOR, AO, and T-AO class support ships, both underway and in port and
- Receive and deliver fleet freight, mail, and personnel to and from combatant and support force ships underway and in port.

It is operated by civil service or contract crews, and is equipped with no defensive weapons. It has two propeller shafts, powered by two commercial Colt-Pielstick 10-PC4.2V diesels on hulls 187-189, and two commercial Fairbanks Morse diesels on the remaining hulls. The commercial diesels were selected for fuel economy and to reduce engine room maintenance and manning requirements. The underway replenishment gear had been developed and proven on previous replenishment oiler classes. The detailed design of the T-AO 187 class was by Avondale Shipyards, and the class was to be built by Avondale Shipyards, Pennsylvania Shipbuilding ("Penn"), and Tampa Shipyard. Hulls 191 and 192 were started by Penn, but not completed before that company went into bankruptcy. Tampa Shipyard was awarded the contract for completion of hulls 191 and 192 but is now bankrupt as well.

Development of the T-AO 187 class was started in December 1981, and the program was baselined at that time. Actual development costs were $15.3 million 1984 constant dollars, 2 percent less than the original estimate. Avondale had previously designed and built the similar but smaller AO 177 Cimarron class replenishment oiler, which had steam propulsion. In spite of that experience, there were design difficulties with the T-AO 187 class, including excessive vibration at high speeds.

Production was started on schedule in November 1982 at Avondale, with a contract for hull 187 with options for hulls 188-190 and a subsequent option for hull 193. Penn received a contract in May 1985 for hulls 190 and 191, with options for hulls 194 and 196, all to be built in a new shipyard opened by Penn. The options on hulls 194 and 196 were transferred to Avondale in June 1988 when it became obvious that Penn was having difficulties fulfilling the contract for hulls 191 and 192. The contract with Penn was terminated for default in August 1989 when Penn went bankrupt. The government awarded Tampa a contract to complete hulls 191 and 192, but the contract was terminated for default in August 1993. Avondale subsequently received options for hulls 195 and

hulls 197-204. Production costs for the originally specified quantity were 6 percent higher than the original estimate. Initial operational capability was in February 1987, 3 months behind schedule.

Two of the T-AO ships, hulls 191 and 192, were declared in excess of requirements by the Navy in October 1994. They were eventually mothballed and delivered to the reserves.

The following acquisition initiatives have been applied to the T-AO 187 Henry J. Kaiser class procurement:

- Use of commercially available propulsion system
- Prototyping of underway replenishment gear
- Competition at the subsystem level during full-scale development
- Independent cost evaluation in April 1979
- Independent test of the underway replenishment gear
- Streamlining of the follow-on procurements
- Dual-sourcing of the production between Avondale and Penn/Tampa
- Dual-sourcing of the production of the underway replenishment gear
- Fixed-price incentive and firm fixed-price contracts for development
- Fixed-price incentive production contracts with Avondale and Penn for hulls 187-192, 194, and 196
- Firm fixed-price contracts with Avondale for options on hulls 194 and 196, and with Tampa for completion of hulls 191 and 192
- Fixed-price incentive with escalation contracts for production of hulls 193 and 195-198
- Fixed-price incentive with escalation for production of hulls 199-204.

Government management of the program has been strongly criticized by Congress and the press. The Navy was concerned enough about Penn Ship's finances that it took out a lien on Penn Ship's assets in case of default. Then, the Navy canceled the lien agreement, leaving itself unsecured. The Tampa shipyard that took over the project also has not been able to perform. [Hackworth, 1995]

The acquisition strategy for the T-AO 187 class had considerable turbulence due to Penn Ship's bankruptcy. Nevertheless, the ships' cost growth was not high.

This page intentionally left blank

REFERENCES

1. Hackworth, David, "Shipyard Contract is Waste at its Worst," Harrisburg, PA Patriot News, August 11, 1995, p. 11.
2. Tibbitts, B.F., and R.G. Keane, Jr., *The Warship Design Process: Making Design Everybodys Job*, Briefing, 1995.

APPENDIX B
TECHNOLOGY COMPARISONS OF U.S. AND FOREIGN SHIPYARDS

Table B-1. Summary of Average Technology Levels for Large U.S. Shipyards and Visited Foreign Competitors

Label	Activity	Technology Level		Weighting	Weighted Level	
		US Shipyards	Foreign Shipyards		US Shipyards	Foreign Shipyards
A1	Plate stockyard and treatment	2.9	2.9	0.500	0.145	0.145
A2	Stiffener stockyard and treatment	2.8	2.9	0.040	0.112	0.116
A3	Plate cutting	3.8	4.0	0.090	0.342	0.360
A4	Stiffener cutting	2.1	3.4	0.080	0.168	0.272
A5	Plate and stiffener forming	2.8	3.2	0.080	0.224	0.256
A6	Subassembly	2.6	3.4	0.120	0.312	0.408
A7	Flat unit assembly	2.9	3.2	0.1030	0.377	0.416
A8	Curved and corrugated unit assembly	2.9	3.4	0.150	0.435	0.510
A9	3D unit assembly	3.1	3.9	0.110	0.341	0.429
A10	Superstructure unit assembly	3.0	3.4	0.100	0.300	0.340
A11	Outfit steelwork	3.0	4.1	0.050	0.150	0.205
A	**STEELWORK PRODUCTION**			**0.156**	**2.906**	**3.457**
B1	Pipework	3.3	3.3	0.190	0.627	0-.627
B2	Engineering	2.8	3.0	0.130	0.364	0.390
B3	Blacksmiths	3.3	3.8	0.050	0.165	0.190
B4	Sheet metal work	2.9	4.3	0.150	0.435	0.645
B5	Woodworking	3.5	3.7	0.100	0.350	0.370
B6	Electrical	3.5	4.0	0.090	0.315	0.360
B7	Rigging	3.0	3.5	0.050	0.150	0.175
B8	Maintenance	3.8	3.6	0.060	0.228	0.216
B9	Garage	3.6	3.8	0.040	0.144	0.152
B10	General Storage	3.6	4.4	0.070	0.252	0.308
B11	Auxiliary storage	3.9	4.5	0.070	0.273	0.315
B	**OUTFIT PRODUCTION AND STORES**			**0.115**	**3.303**	**3.748**

Table B-1. Continued

Label	Activity	Technology Level: US Shipyards	Technology Level: Foreign Shipyards	Weighting	Weighted Level: US Shipyards	Weighted Level: Foreign Shipyards
C1	Module building	3.3	3.9	0.180	0.594	0.702
C2	Outfit parts marshalling	5.0	4.0	0.200	1.000	0.800
C3	Pre-erection outfitting	3.4	4.1	0.210	0.714	0.861
C4	Block assembly	3.8	4.2	0.220	0.836	0.924
C5	Unit and block storage	3.6	4.7	0.070	0.252	0.329
C6	Materials handling	3.6	3.7	0.120	0.432	0.444
C	**OTHER PRE-ERECTION ACTIVITIES**			**0.167**	**3.828**	**4.060**
D1	Ship construction	3.0	3.7	0.090	0.270	0.333
D2	Erection and fairing	2.8	4.0	0.100	0.280	0.400
D3	Welding	3.3	3.6	0.100	0.330	0.360
D4	Onboard services	3.4	4.4	0.060	0.204	0.264
D5	Staging and access	2.6	3.5	0.080	0.208	0.280
D6	Pipework	3.5	4.1	0.100	0.350	0.410
D7	Engine room machinery	3.3	4.5	0.050	0.165	0.225
D8	Hull engineering	3.4	4.5	0.050	0.170	0.225
D9	Sheet metal work	3.5	4.5	0.040	0.140	0.180
D10	Woodwork	2.5	3.7	0.040	0.100	0.148
D11	Electrical	3.1	4.0	0.070	0.217	0.280
D12	Painting	2.6	3.5	0.080	0.208	0.280
D13	Testing and commissioning	4.3	4.7	0.090	0.387	0.423
D14	After launch	3.1	3.5	0.050	0.155	0.175
D	**SHIP CONSTRUCTION**			**0.167**	**3.184**	**3.983**
E1	Layout and material flow	2.6	3.1	0.320	0.832	0.992
E2	General environmental protection	3.1	3.5	0.300	0.930	1.050
E3	Lighting and heating	3.5	3.1	0.160	0.560	0.496
E4	Noise, ventilation and fume extraction	2.8	3.5	0.220	0.616	0.770
E	**LAYOUT AND ENVIRONMENT**			**0.083**	**2.938**	**3.308**
G1	Ship design	3.1	4.0	0.120	0.372	0.480
G2	Steelwork drawing presentation	3.3	4.4	0.100	0.330	0.440
G3	Outfit drawing presentation	3.3	4.5	0.100	0.330	0.450
G4	Steelwork coding system	4.5	5.0	0.070	0.315	0.350
G5	Parts listing procedures	4.5	5.0	0.100	0.450	0.500
G6	Production engineering	3.1	4.0	0.130	0.403	0.520
G7	Design for production	3.1	4.1	0.160	0.496	0.656
G8	Dimensional and quality control	3.0	4.1	0.130	0.390	0.533

Table B-1. Continued

Label	Activity	Technology Level		Weighting	Weighted Level	
		US Shipyards	Foreign Shipyards		US Shipyards	Foreign Shipyards
G9	Lofting methods	4.0	4.5	0.090	0.360	0.405
G	**DESIGN/DRAUGHTING/PRODUCTION ENGINEERING/LOFTING**			**0.166**	**3.446**	**4.334**
H1	Organization of work	2.5	4.4	0.120	0.300	0.528
H2	Contract scheduling	3.8	4.8	0.060	0.228	0.288
H3	Steelwork production scheduling	4.4	4.9	0.070	0.308	0.343
H4	Outfit production scheduling	4.4	4.8	0.060	0.264	0.288
H5	Outfit installation scheduling	4.5	4.9	0.070	0.315	0.343
H6	Ship construction scheduling	4.4	4.8	0.070	0.308	0.336
H7	Steelwork production control	4.0	4.6	0.070	0.280	0.322
H8	Outfit production control	4.0	4.6	0.070	0.280	0.322
H9	Outfit installation control	4.0	4.6	0.080	0.320	0.368
H10	Ship construction control	4.0	4.6	0.080	0.320	0.368
H11	Stores control	4.3	4.8	0.070	0.301	0.336
H12	Performance and efficiency calculations	4.6	4.9	0.050	0.230	0.245
H13	Computer applications	3.8	4.0	0.050	0.190	0.200
H14	Purchasing	4.9	4.8	0.080	0.392	0.384
H	**ORGANIZATION AND OPERATING SYSTEMS**			**0.146**	**4.036**	**4.671**
SHIPYARD TECHNOLOGY LEVEL = $\sum_{A}^{H}$(Sum of Products x Group Weighting)				1.000	3.409	3.989
					3.4	4.0

Source: Storch, A&P Appledore, Lamb, 1994.

This page intentionally left blank

Appendix C

GLOSSARY

APPENDIX C
GLOSSARY

AALC	Amphibious Assault Landing Crafts
ABS	American Bureau of Shipping
AGM	Avondale Gulfport Marine
ASI	Avondale Shipbuilding Industries
ASN	Assistant Secretary of the Navy
ASNE	American Society of Naval Engineers
ATC	affordability through commonality
AWES	Association of West European Shipbuilders
B&W	Burmeister and Wain
BIW	Bath Iron Works
CAD	Computer-Aided Design
CAIV	cost as an independent variable
CALS	computer-aided logistics system
CAM	Computer-Aided Manufacturing
CAS	Cost Accounting Standards
CDR	Contract Design Report
CDRL	contractor data requirements list
CDS	Construction Differential Subsidy
CFE	contractor-furnished equipment
CGRT	compensated gross registered ton
CGT	Compensated Gross Ton
CIM	Computer-Integrated Manufacturing
CNA	Center for Naval Analyses
CODOG	Combined Diesel or Gas Turbine (Powerplant)

COEA	Cost and Operational Effectiveness Analysis
COR	Circular of Requirements
CPAF	Cost Plus Award Fee (contract)
CPFF	Cost Plus Fixed Fee (contract)
CSIS	Center for Strategic and International Studies
DAB	Defense Acquisition Board
DAC	design, acquisition and construction
DARPA	Defense Advanced Research Project Agency
DASN(RDA)	Deputy Assistant Secretary of Navy (Research, Development and Acquisition
DCAA	Defense Contract Audit Agency
DoD	Department of Defense
DOP	Development Options Paper
DSC	Drewry Shipping Consultants
DSM	Design Structure Matrix
DTC	design to cost
dwt	dead weight ton
ECP	Engineering Change Proposal
FASA	Federal Acquisition Streamlining Act of 1994
FM	Family Manufacture
FPAF	Fixed Price Award Fee (contract)
FPD	Fixed Price Development
FPIF	Fixed Price Incentive Fee (contract)
FSD	Full Scale Development
GAO	General Accounting Office
GBS	Generic Build Strategy
GFE	government-furnished equipment
GFI	government-furnished information

GT	Group Technology
HBCM	hull block construction method
HVAC	heating, ventilation, air conditioning
ICAM	Integrated Computer-Aided Manufacturing
IDEF	Integration Definition for Functional Modeling
IGES	Initial Graphics Exchange Specification
IPO	IGES/PDES Organization
IPPD	Integrated Product and Process Development
IPPDT	Integrated Product and Process Development Team
IPT	Integrated Product Teams
IRS	Internal Revenue Service
ITAWDS	Integrated Tactical Amphibious Warfare Data System
JAST	Joint Advanced Strike Technology
KHI	Kawasaki Heavy Industries
LCAC	Landing Craft, Air Cushion
LCC	Life Cycle Cost
ldtd	light displacement tons
LLT	long lead time
LNG	liquid natural gas
MARAD	Maritime Administration
mgt	million gross tons
MHI	Mitsubishi Heavy Industries
MSB	Major Shipbuilding Base
MSSTDP	Mid-Term Sealift Ship Technology Development Program
MTACCS	Marine Tactical Amphibious Command and Control System

MYP	multi-year proc
N/C	numerically controlled
NIDDESC	Navy-Industry Digital Data Exchange Standards Committee
NIST	National Institute of Standards
NNS	Newport News Shipbuilding
NPDM	Navy Program Decision Memorandum
NSRP	National Shipbuilding Research Program
ODS	Operating Differential Subsidy
OECD	Organization for Economic Cooperation and Development
OIPT	Overarching Integrated Product Team
OPEC	Organization of Petroleum Exporting Countries
OR	Operational Requirement
OSC	Ocean Shipping Consultants
OSD	Office of the Secretary of Defense
PARMS	PMS, Participating Managers
PATs	Process Action Teams
PDES	Product Data Exchange Specification
PDR	Preliminary Design Report
PDT	product development teams
PERT	Program Evaluation and Review Technique
PMS	Program Manager
PODAC	Product-Oriented Design and Construction
PPM	Product-Process Model
PTM	Productivity Task Manager
PWBS	product-oriented work breakdown structure
QFD	Quality Function Deployment

REA	Requests for Equitable Adjustment
RFP	Request for Proposal
ROM	Rough Order of Magnitude
RRG	Reversing Reduction Gears
SAE	Society of Engineers
SAJ	Shipbuilders Association of Japan
SAMP	Single Acquisition Master Plan
SAR	Selected Acquisition Report
SBD	simulation-based design
SCA	Shipbuilders Council of America
SCN	Ship Construction Navy
SNAME	Society of Naval Architects and Marine Engineers
SPADES	Ship Production and Design Engineering System
SPECS	Ship Specification
SSC	Sea Systems Controllerate
STEP	Standard Electronic Protocols
SUPSHIP	Supervisor of Shipbuilding, Conversion, and Repair
SURTASS	Surveillance Towed Array Sonar System
SWBS	systems-oriented work breakdown structure
T-ARR	Strategic Sealift Ship
TLR	Top Level Requirement
TMS	Textron Marine System
TOR	Tentative Operational Requirement
TPCG	total program cost growth
TPP	Total Package Procurement
TQM	Total Quality Management
ULCC	ultra large crude carrier

VLCC	very large crude carrier
ZOFM	zone outfitting method
ZPTM	zone painting method

Appendix D

DISTRIBUTION LIST

APPENDIX D
DISTRIBUTION LIST

Office of the Secretary of Defense	No. of Copies
Honorable Paul Kaminski Undersecretary of Defense (Acquisition & Technology) Room 3E933 Pentagon Washington, DC 20301	1
Honorable R. Noel Longuemare Principal Deputy Under Secretary of Defense (Acquisition & Technology) Room 3E1006 Pentagon Washington, DC 20301	1
Dr. George R. Schneiter Director Strategic and Tactical Systems Room 3E130 Pentagon Washington, DC 20301	1
Director Naval Warfare Programs Room 3D1048 Pentagon Washington, DC 20301 ATTN: Dr. Paris Genalis Mr. John McGough	2
Director Defense Procurement Room 3E144 Pentagon Washington, DC 20301 ATTN: Ms. Eleanor R. Spector	1

	No. of Copies
Director, Acquisition Program Integration Room 3E1034 Pentagon Washington, DC 20301 ATTN: Mr. Irving I. Blickstein	1
Deputy Under Secretary of Defense Acquisition Reform Room 3E1034 Pentagon Washington, DC 20301 ATTN: Ms. Colleen A. Preston	1
Assistant Deputy Under Secretary of Defense (Systems Acquisition) Room 2A330 Pentagon Washington, DC 20301 ATTN: Donna E. Richbourg	1
Program Analysis and Evaluation Director Naval Forces Division Room 2D312 Pentagon Washington, DC 20301 ATTN: Mr. Thomas L. Gibson	1
Program Analysis and Evaluation Director, Weapon System Cost Analysis Division Room 2C310 Pentagon Washington, DC 20301 ATTN: Mr. Gary R. Bliss	1
Program Analysis and Evaluation Operation Analysis and Procurement Planning Room 2D278 Pentagon Washington, DC 20301 ATTN: Dr. Tzee-Nan Lo	1
Defense Advanced Research Projects Agency Tactical Technology Office Virginia Square Plaza Arlington, VA 22203 ATTN: Mr. Stan Siegel	1

	No. of Copies
Defense Advanced Research Projects Agency Simulation Based Design Virginia Square Plaza Arlington, VA 22203 ATTN: Mr. Gary Jones	1
Defense Advanced Research Projects Agency MARITECH Program Office 4301 N. Fairfax Drive, Suite 700 Arlington, VA 22203 ATTN: Mr. Robert Schaffran	1

Department of the Navy

Honorable John Douglas Assistant Secretary of the Navy (Research, Development & Acquistion) Room 4E732 Pentagon Washington, DC 20350	1
Office of the Assistant Secretary of the Navy (Research, Development and Acquisition) Director, Acquisition Reform Center of Excellence 2211 S. Clark Place CP5/Room 924 Arlington, VA 22244-5104 ATTN: Ms. Karen D. Sorber	1
Deputy Assistant Secretary of the Navy (Ship Programs) Room 5E813 Pentagon Washington, DC 20350 ATTN: Mr. Mike Hammes	1
Deputy Chief of Naval Operations Resources, Warfare Requirements & Assessments Director Assessment Division (N81) Room 4A530 Pentagon Washington, DC 20350 ATTN: RADM T. B. Fargo	1

	No. of Copies
Deputy Chief of Naval Operations Resources, Warfare Requirements & Assessments Director Surface Warfare Division (N86) Room 4E552 Pentagon Washington, DC 20350 ATTN: RADM P. J. Coady CMD Mike Bosworth	2
Deputy Chief of Naval Operations Resources, Warfare Requirements & Assessments Director Surface Warfare Plans, Programs, Requirements Branch (N863) Room 4D547 Pentagon Washington, DC 20350 ATTN: RADM T. F. Marfiak	1
Deputy Chief of Naval Operations Resources, Warfare Requirements & Assessments SCN Appropriations Manager & Assistant for Ship Design (N86F) Room 4D529 Pentagon Washington, DC 20350 ATTN: CAPT G. M. Musick III	1
Deputy Chief of Naval Operations Resources, Warfare Requirements & Assessments Director Amphibious Warfare Branch (N853) Room 5E613 Pentagon Washington, DC 20350 ATTN: CAPT G. P. Marvin	1
Commander Naval Sea Systems Command Room 12E10 National Center 3 Arlington, VA 22202 ATTN: VADM G. R. Sterner	1
Naval Sea Systems Command Deputy Commander for Engineering National Center 3 Arlington, VA 22202 ATTN: RADM M. S. Firebaugh	1

	No. of Copies
Naval Sea Systems Command Director Surface Ship Design & System Engineering Group National Center 3 Arlington, VA 22202 ATTN: CAPT R. C. Percival	1
Naval Sea Systems Command Director Naval Shipyard & SUPSHIP Management & Field Activity Crystal Park 5 Room 1174 Arlington, VA 22202 ATTN: RADM T. J. Porter	1
Naval Sea Systems Command Deputy Commander Surface Ship Directorate National Center 3 Room 9S08 Arlington, VA 22202 ATTN: Mr. Jesse Atkins	1
Naval Sea Systems Command Program Manager Affordability Through Commonality (SEA 03R3) National Center 3 Arlington, VA 22202 ATTN: Mr. Jeff Hough	1
Naval Sea Systems Command Program Manager Combatant Craft/Service Craft/Amphibious Acquisition Programs (PMS 300) National Center 3 Arlington, VA 22202 ATTN: CDR R. W. Havel	1
Naval Sea Systems Command Program Manager Mine Warfare Ship Program Office (PMS 303) National Center 3 Room 10S10 Arlington, VA 22202 ATTN: Mr. J. D. Collie	1

	No. of Copies
Naval Sea Systems Command Program Manager Aircraft Carrier Program (PMS 312) National Center 3 Room 8W08 Arlington, VA 22202 ATTN: CAPT K. P. Perkins	1
Naval Sea Systems Command Program Manager Surface Ship Program Management Office (PMS 335) National Center 3 Room 9E08 Arlington, VA 22202 ATTN: CAPT J. P. McComas	1
Naval Sea Systems Command Program Manager Amphibious Warfare Program (PMS 377) National Center 3 Room 8E06 Arlington, VA 22202 ATTN: Mr. E. E. Shoults	1
Naval Sea Systems Command Program Manager Support Ships, Boats & Craft Programs (PMS 325) National Center 3 Room 6E58 Arlington, VA 22202 ATTN: CAPT R. E. Williams	1
Naval Sea Systems Command Program Manager Strategic Sealift Program Office (PMS 385) National Center 3 Room 11E08 Arlington, VA 22202 ATTN: CAPT D. Whiddon	1

	No. of Copies
Naval Sea Systems Command Program Manager Aegis (PMS 400) National Center 2 Room 10N18 Arlington, VA 22202 ATTN: RADM G. A. Huchting	1
Naval Sea Systems Command NAVSEA 017 (Cost Estimating and Analysis) Washington, DC 20362 ATTN: Mr. Ottar Rohrstaff	1
NAVSEA Acquisition Reform (Code 91AR) 2531 Jefferson Davis Highway Arlington, VA 22242 ATTN: Mr. Tom Demas	1
Space and Naval Warfare Systems Command Program Manager, Fixed Distributed System Department of the Navy Washington, DC 20363-5100 ATTN: Mr. Robert L. Hobart	1
Naval Center for Cost Analysis Crystal Gateway North, Room 400 Arlington, VA 22202 ATTN: Director	1
NAVSEA Shipbuilding Support Office Philadelphia Naval Shipyard Code 2900, Building 712 Philadelphia, PA 19112 ATTN: Mr. Michael Maryiano	1
Office of Naval Research 800 Quincy St., Ballston Tower No. 1 Arlington, VA 22217-5000 ATTN: Mr. F.E. Saalfield	1
Commander Military Sealift Command Room 401, Building 210 Washington Navy Yard Washington, DC ATTN: VADM P. Quast	1

	No. of Copies
Naval Surface Warfare Center, Carderock Division Bethesda, MD 20034 ATTN: CAPT J. E. Baskerville	1
Naval Surface Warfare Center, Carderock Division Shipbuilding Technologies Office (Code 203) Bethesda, MD 20034 ATTN: Mr. Mike Wade	1
Supervisor of Shipbuilding, Conversion and Repair Bath, ME 04530	1
Supervisor of Shipbuilding, Conversion and Repair Naval Support Activity, Building 16 New Orleans, LA 70142-5070	1
Supervisor of Shipbuilding, Conversion and Repair Newport News, VA 23607	1
Supervisor of Shipbuilding, Conversion and Repair P.O. Box 7003 Pascagoula, MS 39568-7003	1
Superintendent U.S. Naval Postgraduate School Monterey, CA 93943-5100 ATTN: Naval Engineering Department Management Department	2
Commanding Officer Naval War College Newport, RI 02841-5010 ATTN: Library Management and Defense Economics Department	2

Shipyards and Ship Design Firms

Avondale Industries, Inc. P.O. Box 50280 New Orleans, LA 70150-0280 ATTN: Mr. Ron J. McAlear	1

	No. of Copies
Bath Iron Works Corporation 700 Washington Street Bath, ME 04530 ATTN: Mr. Buzz Fitzgerald, President	1
Bath Iron Works 2341 Jefferson Davis Highway, Suite 1100 Arlington, VA 22202 ATTN: Mr. Gerard Lamb	1
Ingalls Shipbuilding P.O. Box 149 Pascagoula, MS 39568-0149 ATTN: Mr. Jerry St. Pe', President	1
Ingalls Shipbuilding Washington Operations 1725 Jefferson Davis Highway, Suite 601 Arlington, VA 22202 ATTN: Mr. Paul Martineau	1
McDermott Shipbuilding 1450 Poydras Street, Suite 1709 New Orleans, LA 70112 ATTN: Mr. H. Brinson Miles III, Vice President	1
National Steel and Shipbuilding Company P.O. Box 85278 San Diego, CA 92186-5278 ATTN: Mr. Alfred Lotler, Jr.	1
National Steel and Shipbuilding Company Washington Operations P.O. Box 16614 Arlington, VA 22215 ATTN: Mr. James Temenak	1
Newport News Shipbuilding 4101 Washington Avenue Newport News, VA 23607 ATTN: Office of the President	1

	No. of Copies
Newport News Shipbuilding Airport Plaza 1, Suite 1100 2711 Jefferson Davis Highway Arlington, VA 22202 ATTN: Manager, Navy Programs	1
Gibbs & Cox, Inc. 1235 Jefferson Davis Highway Arlington, VA 22202 ATTN: Mr. Robert J. Scott	1
J.J. McMullen Associates Century Building, Suite 715 2341 Jefferson Davis Highway Arlington, VA 22202 ATTN: Mr. Ron D'Arcy CAPT Barry Tibbits, USN (Ret.) Michael D. Bancroft	3

Universities

Clemson University Department of Economics 223 Sirrine Hall Clemson, SC 29634-1309 ATTN: Dr. John Warner	1
George Mason University School of Law 3401 North Fairfax Drive Arlington, VA 22201 ATTN: Mr. William E. Kovacic	1
Massachusetts Institute of Technology Department of Ocean Engineering Cambridge, MA 02139 ATTN: Professor A. Douglas Carmichael	1
Massachusetts Institute of Technology Alfred P. Sloan School of Management Room E53-347 50 Memorial Drive Cambridge, MA 02142-1347 ATTN: Steven D. Eppinger	1

	No. of Copies
Massachusetts Institute of Technology Center for Technology, Policy, and Industrial Development Cambridge, MA 02139 ATTN: Mr. Daniel E. Whitney	1
University of California Department of Naval Architecture and Offshore Engineering Berkeley, CA 94720 ATTN: R. W. Yeung	1
University of Michigan Department of Naval Architecture and Marine Engineering Ann Arbor, Michigan 48109 ATTN: Professor William Vorus	1
University of New Orleans Department of Naval Architecture Lakefront New Orleans, LA 70148 ATTN: Dr. Robert Latorre	1
Webb Institute of Naval Architecture Glen Cove, NY 11542 ATTN: Professor Jacques Hadler	1

Other Organizations

US Air Force Academy DFEG 2354 Fairchild Drive, Suite 6K12 US Air Force Academy, CO 80840-6238 ATTN: Dr. Peter Taylor	1
U.S. Department of Transportation Maritime Administration 400 Seventh Street, S.W. Washington, DC 20590 ATTN: Mr. Joseph A. Byrne	1

	No. of Copies
National Research Council Commission on Engineering and Technical Systems 2101 Constitution Avenue Washington, DC 20418 ATTN: Mr. Robert A. Sielski	1
American Shipbuilders Association 1755 Jefferson Davis Highway, Suite 1105 Arlington, VA 22202 ATTN: Mr. Thomas Bowler	1
Shipbuilders Council of America 4301 N. Fairfax Drive, Suite 330 Arlington, VA 22203 ATTN: Mr. Silas O. Nunn	1
Center for Naval Analyses P.O. Box 16268 Alexandria, VA 22302-0268 ATTN: Mr. William D. O'Neil	1
Defense Technical Information Center 8725 John J. Kingman Road, Suite 0944 Fort Belvoir, VA 22060-6218	2
Institute for Defense Analyses 1801 N. Beauregard St. Alexandria, VA 22311	20
Total Distribution	106

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1996	Final

4. TITLE AND SUBTITLE
Assessment of Options for Enhancing Surface Ship Acquisition

5. FUNDING NUMBERS
DASW01 94 C 0054
Task T-F1-1271
Task A-194

6. AUTHOR(S)
L. Dean Simmons, Colin P. Hammon, Robert E. Kuenne, James W. Lisanby, Neang I. Om, Dean A. Rains, Kevin J. Saeger, Karen W. Tyson, Harry Williams

7. PERFORMING/ORGANIZATION NAME(S) AND ADDRESS(ES)
INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street
Alexandria, VA 22311

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Paper P-3172

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Director, Strategic and Tactical Systems
Room 3E130, The Pentagon
Washington D.C. 20301

Defense Advanced Research Projects Agency
Virginia Square Plaza
Arlington, VA 22203

Director, FFRDC Programs
2001 N. Beauregard Street
Alexandria, VA 22311

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This study examines options for enhancing the ship acquisition process so as to enable effective and efficient Navy ship procurement and at the same time help to strengthen the shipbuilding industry. Based on information obtained through extensive interviews and discussions with appropriate Government agencies, Navy offices, and shipbuilders in the United States and overseas, this study identifies and assesses a variety of means to improve the processes by which the Navy designs and builds new ships and manages their acquisition. Particular attention is focused on acquisition strategies and program management, ship design and production practices, and the implications of increased commercial construction on naval shipbuilding. The results of the study should benefit the Department of Defense as well as the nation's shipbuilding industry.

14. SUBJECT TERMS
Surface Ship Acquisition, Ship Design, Ship Production, Commercial Shipbuilding, Naval Shipbuilding

15. NUMBER OF PAGES
299

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102